The Development of Phonological and Orthographic Processing Strategies in Readers with a Specific Reading Disability Compared to Normally Achieving Readers.

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Abstract

The self-teaching model of reading acquisition proposed by Share (1995, 1999) suggests that phonological decoding may be the principal means for becoming skilled at word recognition. Given that individuals with a specific reading disability (SRD) have been shown to have a phonological processing deficit (Rack et al., 1992), the lack of proficiency in these skills could have detrimental effects on orthographic processing skills. In contrast, Lennox and Siegel (1994) argue that the cognitive profile of children who have a specific reading disability (SRDs) might include deficient phonological skills and superior orthographic skills. In a two-year longitudinal study, SRDs in Grades 3, 5, and 7 and their chronological age (CAMs) and reading age (RAMs) matched controls (*N*=98) performed a range of standardised and experimental tasks to investigate the development of phonological and orthographic component processing skills. Although SRDs made significant gains on isolated word recognition tasks over time, they did not improve to the same extent as RAMs. This was largely attributed to a phonological processing deficit given that, in comparison to controls, SRDs were significantly less accurate on nonword reading, phoneme deletion, and phonological coding tasks and did not improve significantly over time for the latter two tasks. SRDs demonstrated a particular difficulty with phonological analysis of visual stimuli and were more likely than controls to use an orthographic strategy to perform this task. Although SRDs did not demonstrate a deficit for synthesis tasks, they did show an atypical developmental pattern compared to RAMs. SRDs in Grade 3 had difficulty discriminating between real word targets and pseudohomophone foils on an orthographic coding task compared to controls whereas older SRDs performed similarly to RAMs. Although all SRDs improved on this task, the youngest group appeared to develop less accurate orthographic

representations. In discriminating between nonwords containing legal letter strings and those containing letter strings in positions that never occur in the English language, all groups performed similarly indicating that the participants had attained a sufficient level of orthographic knowledge required to perform this task. Orthographic strategy use and coding skills appeared to be relatively intact in comparison to phonological processing skills for SRDs. However, there was insufficient evidence to conclude that SRDs compensate for their phonological deficit with superior orthographic skills given that there were no orthographic tasks where SRDs performed better than would be expected given their reading age. Furthermore, in addition to an atypical developmental pattern for phonological processing skills, SRDs showed a protracted developmental course for some measures of orthographic processing. These findings support Share's (1995, 1999) idea that the acquisition of orthographic representations is largely dependent on phonological processing skills.

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Introduction

Children with a specific reading disability (SRD) present with a deficit in reading ability that cannot be attributed to sensory or neurological damage, lack of educational opportunity, or low intelligence. Given that between 4% and 7% of children are considered to have a specific reading disability or SRD (Snowling, 1998), research in this area is important to assist in the processes of diagnosis, remediation, and prevention. This thesis is aims to obtain information from experimental measures about the theoretical underpinnings of SRD. In general terms, it is primarily concerned with developing a greater understanding of how the processes involved in reading development in SRDs may deviate from the normal course of reading acquisition.

This thesis is not concerned with reading acquisition from the perspective of reading for meaning but rather the development of component processes of word recognition independent of sentential context. Although it is recognised that many theories of word recognition incorporate procedures for deriving meaning from isolated words by way of a semantic processing mechanism, a discussion or overview of this aspect is not pertinent to the aims of this thesis. Therefore, the first chapter will outline theoretical and computational models that attempt to elucidate or simulate visual word recognition, with a primary focus on phonological and orthographic processes given that they are heavily implicated in the models of reading acquisition to be outlined in Chapter Two.

Chapters Three and Four provide an overview of the current knowledge about the relative strengths and weaknesses of SRDs in terms of phonological and orthographic processes. Although it is a well known finding that SRDs differ from normally achieving readers with respect to aspects of reading that place heavy demands on phonological processing (e.g., Rack, Snowling, & Olson, 1992), there is less consistent evidence regarding the role of orthographic processing skills in SRDs. Therefore, this thesis will measure the development of both phonological and orthographic component processes over a two-year longitudinal study. The main aim of this thesis is to determine whether a phonological deficit has a detrimental impact upon the development of orthographic processing skills or whether SRDs possess intact orthographic processing skills that compensate for their phonological deficit.

Although there have been similar developmental studies previously reported in the literature, this thesis incorporates experimental measures that provide an extension to phoneme deletion measures that have been used in studies with SRDs. This will involve an assessment of accuracy and flexibility in utilising orthographic and phonological strategies to complete synthesis and analysis tasks in addition to other phonological and orthographic coding measures. It will also investigate SRDs at different age levels to determine whether developmental changes over time depend upon the age of the participant, as many previous studies have tended to use a single age group.

Models of Word Recognition

Models of word recognition help to answer the question of how we are able to recognise a visually presented word or what processes are engaged when we read a word. One model that has received a great deal of attention is the dual-route model first proposed by Coltheart (1978). The basic concept underlying dual route theory is the idea that there are two processing routes or mechanisms for recognising printed words. Each of these routes is thought to have a distinct function. These routes are the direct lexical access or orthographic route and the indirect sublexical access or phonological route. The proposal that there are two routes by which we access a word is based on the observation that skilled readers are able to read aloud correctly two different types of letter string, the pronounceable nonword and the irregular or exception word.

Coltheart (1985) reports that the role of the phonological route is to transform an orthographic representation into a phonological code using grapheme-phoneme correspondence (GPC) rules. In order to generate the pronunciation of a word using this route, three tasks are conducted in sequence, graphemic parsing, phoneme assignment, and blending. Firstly, for any given word, the letter string has to be parsed or broken down into a series of graphemes. Using GPCs, phonemes or sounds are assigned to each grapheme. Finally, the phonemes are blended together to pronounce the word. This process of translation is typically associated with identifying unfamiliar words or nonwords that need to be decoded using a phonological route because it is assumed that there is no accurate representation stored in the mental lexicon.

However, if this were the only process available to recognise words, this would lead to incorrect pronunciations of irregular or exception words in the English language because these do not follow GPC rules. In order to pronounce these types of words, word specific information needs to be accessed from the mental lexicon using the orthographic route. When a familiar irregular word is encountered, it is proposed that it is recognised by being directly accessed from the lexicon based on its orthography or visual features. This process is engaged when familiar words are encountered, irrespective of whether they are irregular or regular, because the orthographic route allows faster and more efficient access whereas the processing in the phonological route requires more resources (Paap & Noel, 1991).

Although the evidence is not consistent (e.g., Hanley & McDonnell, 1997), there are many proponents of the view that word recognition is phonologically mediated for both good and poor readers (Johnston, Rugg, & Scott, 1987) and that the phonological route is automatically mobilised when a word is encountered, regardless of whether the word is successfully identified using the orthographic route (Doctor & Coltheart, 1980; Folk & Morris, 1995; Frost, 1998; Lesch & Pollatsek, 1993; Van Orden, 1987). This suggests that these processes are not activated in isolation of one another.

A computational version of the dual-route model, the dual-route cascade or DRC model, has been developed (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). It contains two procedures for converting print to speech, a lexical lookup procedure and a grapheme-to-phoneme rule (GPC) procedure. It is a computational model that exists as a complete computer program that takes letters as input and generates a phonemic representation as output. In earlier conceptualisations of the model (Coltheart et al., 1993), the GPC route was exposed to the printed forms of words and their pronunciations and effectively learnt the grapheme-phoneme rules embodied in the training set of words. The GPC rules were automatically learned from exposure to the spellings and pronunciations of real words. The system was then able to apply these rules to new letter strings it had not seen before and was able to demonstrate accurate nonword reading. This demonstration was largely used to highlight the inability of an alterative model (Seidenberg & McClelland, 1989) to simulate human behavioural data for nonword reading accuracy.

Compared to other computational models (Plaut, McClelland, Seidenberg, & Patterson, 1996; Siedenberg & McClelland, 1989; Zorzi, Houghton, & Butterworth, 1998), computational learning is no longer a feature of the current version of the DRC model given that it does not claim to model reading acquisition (Coltheart et al., 2001). In this case the DRC proposes a serial theory of assembled phonology whereby GPC rules are encoded in the architecture rather than learned so that every grapheme is represented by a corresponding phoneme unit. When confronted with a letter string for translation, the GPC rules are searched letter by letter from left to right until a match is found for each grapheme represented in the letter string. In contrast, the lexical route operates by activating orthographic lexical units based on the letter units represented in the stimulus word. For each of these units, there is a phonological lexical unit that activates the phonemes required for pronunciation.

These routes do not operate independently of one another as they share the same initial processing stage, the letter identification stage, which delivers its output to two different destinations, the orthographic input lexicon and the GPC rule system. The two routes also share a final processing stage, as both deliver a pronunciation (Coltheart et al., 2001; Coltheart & Rastle, 1994). The DRC model adopts a cascaded approach as Coltheart et al. (2001) propose that it is more consistent with behavioural data that suggests that activation occurs in both routes when a letter string is encountered. Therefore, a pronunciation is thought to be derived from the input of both the GPC and lexical routes by using the levels of activation they contribute to the phoneme system. For example, nonword reading is typically associated with a nonlexical procedure for pronunciation but the DRC model suggests that nonwords also activate orthographically similar words in the orthographic lexicon. The phonemic activation that this generated is paired with the results from the GPC route to facilitate nonword naming. This has been further exemplified by results showing that if the lexical route is disabled, nonword naming times increase (Coltheart & Coltheart, 2000, cited in Coltheart et al., 2001).

The DRC model is evaluated by determining how well it can simulate effects obtained in a variety of experiments on visual word recognition and reading aloud in human participants. For example, Coltheart and Rastle (1994) report data that supports a major premise of the model, that phonology is assembled through serial processing of the letter string from left to right. They used the DRC model to generate pronunciations of low frequency exception words and hypothesised that naming latency was influenced by the position of irregularity within the word. Irregularity within a word creates conflict between the phonological representations generated by the lexical and nonlexical routes and increases naming latencies. Coltheart and Rastle (1994) found that the effect of low frequency exception words on naming latencies decreased as the position of the exceptional phoneme moves from left to right, a finding which they then replicated with human participants.

In summary, dual route theorists have identified certain facts about reading that they believe can only be explained by positing the existence of separate lexical and nonlexical routes. Coltheart et al. (1993) postulate that the DRC model can successfully account for skilled reading of nonwords, regular, and exception words, lexical decisions, and acquired and developmental dyslexia. Further work reported by Coltheart et al. (2001) reviews other reading phenomena that the model has been able to simulate, such as frequency and lexicality effects, and suggests that the DRC model is the only current computational model that can successfully multi-task. The model is now being adapted to account for polysyllabic reading (Rastle & Coltheart, 2000) and to model word recognition in the German language (Ziegler, Perry, & Coltheart, 2000). A connectionist model of word recognition in the French language has also been conceptualised that shares some features of the DRC model in that it accounts for two distinct global (real word) and analytic (nonword) reading procedures (Ans, Carbonnel, & Valdois, 1998).

The dual route model has undergone much criticism and should by no means be considered the only theory available for explaining the processes of word recognition. For example, Barron (1986) argued that visual word recognition processes could be accommodated within a single lexical model. Seidenberg and McClelland (1989) conceptualised this idea within a parallel distributed processing

(PDP) model. The key feature of the model is the proposal that there is a single, uniform procedure for computing a phonological representation (i.e., a 'pronunciation') from an orthographic representation that is applicable to all types of letter string including regular words, exception words, and nonwords. In contrast to dual-route conceptualisations, the model does not include a lexical lookup procedure because it does not contain a lexicon in which individual entries correspond to individual words. Furthermore, it does not contain a set of pronunciation rules. The model operates using a single mechanism that learns to process all types of letter strings through experience with spelling-to sound correspondences implicit in the set of words from which it learns.

The general framework for lexical processing adhered to by the PDP model assumes that reading involves the computation of three types of codes, orthographic, phonological, and semantic. Each of these codes is assumed to be a distributed representation or a pattern of activation distributed over a number of representational units. Processing is interactive across the three levels such that activation at one level influences activation at another level and is mediated by connections among units through a system of hidden units.

Seidenberg and McClelland (1989) implemented only part of this general framework and used a simplified model that removes the semantic and contextual levels. Furthermore, there is no feedback from the phonological level to the hidden units. Therefore, the phonological representations cannot influence the construction of representations at the orthographic level. In this version of the model there are sufficient units to allow any letter and phoneme sequence to be represented. The network has no initial knowledge of particular correspondences between spelling and sound. The model must learn these relationships from exposure to letter strings and corresponding strings of phonemes and by adjusting the strengths of connections to more closely approximate the target activation.

After training the model by exposing it to monosyllabic words, Seidenberg and McClelland (1989) examined how the model performed on different types of words that were used in behavioural studies. Since the model was trained on a large set of words, it could be tested using the same items that were used in specific experiments with human participants. Coltheart et al. (1993) considered how well the PDP model could account for this data. The model incorrectly pronounced only 2.7% of words and most of these errors were in response to low-frequency exception words, which is consistent with data collected in naming latency experiments with human participants. Therefore, there is both quantitative and qualitative evidence supporting the accurate simulation of exception word reading by the model.

Seidenberg and McClelland (1989) reported some simulation data using nonwords as input but did not report what proportion of nonwords the model read correctly. Besner, Twilley, McCann, and Seergobin (1990) conducted an analysis of accuracy of nonword pronunciations and found that the model could not read nonwords as well as it could read words and performance on nonword reading fell significantly below that of skilled readers. Seidenberg and McClelland (1990) conceded that the model does not read nonwords as well as people can, but argued that this reflects a deficiency in the training set of words rather than a problem with the overall model. However, when the DRC model was trained using the Seidenberg and McClelland

(1989) database and was exposed to the same nonwords, the DRC model read them with 98% accuracy (Coltheart et al., 1993). This suggests that the inability to read nonwords accurately was not due to the training words, but more to do with how word identification processes were represented by the model. When the Seidenberg and McClelland (1989) model was modified with improved orthographic and phonological representations, Seidenberg, Plaut, Petersen, McClelland, and McRae (1994) found that there was no longer a deficit in nonword performance for the connectionist model compared to the DRC model (Coltheart et al., 1993).

A third perspective for considering word recognition processes is the analogy model first proposed by Glushko (1979) that suggests that both the lexical and nonlexical processes can operate in conjunction to pronounce any kind of letter string. Therefore, it is postulated that these processes do not exist as separate mechanisms but share a common knowledge base. Glushko (1979) focused on the functional properties of the lexical and nonlexical knowledge bases rather than viewing them as separate mechanisms. He proposed that words and nonwords are pronounced through the integration of orthographic and phonological information from a number of sources that are activated in parallel.

As letter strings are identified, parallel activation of orthographic and phonological knowledge from a number of sources in memory is thought to occur. This knowledge could include the stored pronunciation of the letter string, pronunciations of words that share features with the letter string, and information about the spelling-to-sound correspondences of various subparts of the letter strings. Glushko (1979) proposed that pronunciation occurs by activation and synthesis. The information that is activated by the letter string is modified in order to synthesise a pronunciation.

Glushko (1979) argued that a letter string is not read aloud by retrieving a single pronunciation from memory or by employing abstract spelling-to-sound rules. Words and nonwords are pronounced using similar kinds of knowledge, the pronunciations of words that resemble them and specific spelling-to-sound rules for multi-letter spelling patterns. Effectively, this position asserts that the lexical and nonlexical mechanisms work in unitary fashion for every letter string.

A connectionist model that is most consistent with analogy models of word recognition has been postulated by Zorzi, Houghton, and Butterworth (1998). The model utilises larger units at the onset-rime level, although phonological and orthographic representations are still at the phoneme and letter level. Unlike other connectionist models there are no hidden units and this was designed to represent a lack of lexical representations and led to regularisation errors. Therefore, this two-layer model was not adequate for exception words and a hidden layer was incorporated to mediate connections between spelling and sound to deal with irregularity while still maintaining a direct link between orthography and phonology. For sublexical assembly, the phonology of any letter string was computed using the most common spelling-sound relationships. This model appears similar to the DRC model in that it appears to encapsulate a lexical and sublexical route. However, the key differences are that although the model may develop implicit rules, a rule-based system was not explicitly specified, and there is no orthographic lexicon. Rather, it provides multiple sources from which a pronunciation can be derived.

Although this thesis does not aim to assess which model best accounts for human behavioural data, this review has established that, despite the conceptual differences between the models outlined above, the common feature shared by them is that they all accommodate phonological and orthographic representations, although the nature of these representations and connections between them may differ depending on the underlying premise of the model.

Models of Reading Acquisition

Many earlier theories of reading development proposed that reading development unfolds in a sequence of stages. For example, Marsh, Freidman, Welch, and Desberg (1981) propose a four-stage theory of reading development where the first two stages are based on rote learning and guessing, initially based on contextual information but becoming more sophisticated and based on visual similarity and other visual cues. The later stages are characterised by decoding, which again becomes more sophisticated as they develop a more consolidated rule base for decoding words. Although Marsh et al. (1981) assume that it is an increase in sight word vocabulary that causes the child to move into a sequential decoding stage, Stuart and Coltheart (1988) cite evidence to the contrary that suggests that it is the development of phonic skills that leads to an increase in vocabulary. Marsh et al.'s (1981) model is also incompatible with models of skilled adult reading such as the dual-route model because it describes a well-developed non-lexical translation route but does not describe a means for direct lexical access.

Frith (1985) proposed a three-phase theory of reading acquisition in which each phase is characterised by a particular reading strategy. In the logographic phase, the child can instantly recognise familiar words based on salient graphic features. The child has no means for reading unfamiliar words presented in isolation but will use context to guess unfamiliar words based on text. During the alphabetic phase, the child knows and uses correspondences between individual graphemes and phonemes. Words are sequentially decoded grapheme by grapheme. The child can generate pronunciations for both unfamiliar words and non-words but will not necessarily generate the correct pronunciation. In contrast to Marsh et al.'s (1981) model, the child is able to parse the letter string into graphemes rather than single letters. In the final phase, an orthographic strategy is adopted where words are instantly analysed into orthographic units without phonological conversion. However, in this model, it is unclear how the intermediate phase of phonological decoding relates to the development of the orthographic strategy.

The stage theories that have been outlined assume that all children pass through the same stages in the same order. However, Stuart and Coltheart (1988) argue that the process of reading acquisition may vary depending on the phonological skills of the beginning reader. A review of the earlier literature on the development of phonological awareness concluded that there is significant evidence that phonological awareness has a causal role in learning to read (Wagner & Torgeson, 1987). Stuart and Coltheart (1988) postulate that children who are phonologically skilled before learning to read might use these skills in early reading development. In contrast, beginning readers who are not phonologically skilled may initially approach reading as a visual memory task. Stuart and Coltheart (1988) investigated this hypothesis by assessing the phonological skills of pre-literate children and followed their progress in reading acquisition over a four-year period to determine whether there were any qualitative differences that could be attributed to different levels of phonological skill.

Stuart and Coltheart's (1988) view is that children's phonological state at the time when they are beginning readers is crucial to their subsequent development. In their study, knowledge of both letter names and sounds was significantly correlated with preschool phonological awareness. Furthermore, baseline levels of phonological knowledge became a significant predictor of reading age in the first year of school. Therefore, phonological skills and knowledge are useful to beginning readers and can be utilised as they learn to read. Children without such knowledge and skills will view the task of learning to read as one of committing visual strings to memory. Children who fit this profile could be regarded as logographic readers relying mainly on a rote learning strategy to develop a sight word vocabulary.

Stuart and Coltheart (1988) do not limit the role of phonological processing in reading development to sequential decoding of a letter string from left to right. Instead, they propose that children are able to use their phonological knowledge and skills to generate a route for direct lexical access. Similarly, Aaron, Joshi, Ayotollah, Ellsberry, Henderson, and Lindsey (1999) argue that the transition from beginning to skilled reading is essentially represented by a transition from being predominantly a decoder to being predominantly a sight word reader. They utilised naming speed as an index of sight word reading and found that somewhere between Grades 3 and 4, children have mastered basic reading skills and start utilising sight word reading. Furthermore, poor decoding skills were strongly related to poor sight word reading skills indicating that these skills are not independent of each other and that sight-word reading appears to be based on decoding skills.

Consistent with this hypothesis is the model of reading acquisition that describes phonological decoding (or print-to-sound translation) as a self-teaching mechanism that enables beginning readers to acquire detailed orthographic representations necessary for rapid, autonomous visual word recognition (Jorm & Share, 1983; Share 1995, 1999). This model proposes that it is the ability to translate printed words independently into their spoken equivalents that is central to reading acquisition. The self-teaching hypothesis proposes that each successful decoding encounter with an unfamiliar word provides an opportunity to acquire word-specific orthographic information. Both adult skilled readers and young children only have to be exposed to a word a relatively small number of times to generate an accurate orthographic representation of the word. Both word-specific and general orthographic knowledge is obtained. It is essential to obtain word-specific orthographic information in order to become a skilled reader because the majority of words are then efficiently and directly accessed from the lexicon. However, phonological decoding may be the principal means by which people become skilled at word recognition.

Thus, in contrast to stage-based theories, Share (1995, 1999) adopts an item-based perspective in which word recognition depends on how often the reader is exposed to a word, how the word is identified, and whether word identification is successful. Therefore, high frequency items are likely to be recognised automatically with minimal phonological processing from the earliest stages of reading acquisition. Novel or less familiar items that do not have an orthographic representation will need to be phonologically decoded in order to generate a correct pronunciation.

The self-teaching mechanism is not restricted to beginning readers but can be implemented by skilled readers when novel letter strings appear in natural text. The self-teaching mechanism facilitates reading acquisition of both skilled and unskilled readers and enables a gradual, unobtrusive expansion of the orthographic lexicon. The self-teaching mechanism is regarded as largely unobtrusive as it does not require a great deal of cognitive effort and therefore, does not disrupt the process of comprehension.

Share (1995, 1999) explains that the process of phonological decoding becomes increasingly 'lexicalised' during reading acquisition. Beginning readers master an initial set of simple one-to-one correspondences between print and sound, which is refined as they gain more orthographic knowledge. Some limited but functional self-teaching skills may exist at the very earliest stages of learning to read prior to the development of conventional decoding skills. As demonstrated by Stuart and Coltheart (1988), letter-sound knowledge and phonemic awareness are both implicated as critical co-requisites for reading acquisition and represent early self-teaching attempts. These partial decoding skills may not lead to correct pronunciation of words presented in isolation but beginning readers use contextual information to supplement low level decoding. The initially incomplete and over-simplified representation of English spelling-to-sound correspondences becomes modified and refined with increasing exposure to print. A more complex, accurate, and highly sophisticated understanding of the relationships between orthography and phonology evolves. Basic knowledge structures utilised by beginning readers provide a catalyst for developing the complex set of spelling-to-sound rules that is used by skilled readers.

The self-teaching mechanism involves two component processes, phonological and orthographic, that make independent contributions to the acquisition of word recognition skills. The phonological component reflects the ability to use knowledge of spelling-to-sound relationships to identify unfamiliar words whereas the orthographic component reflects the ability to store and retrieve word-specific orthographic information. Proficiency in visual/orthographic processing influences the speed and accuracy with which orthographic representations are acquired and is heavily dependent on the successful operation of the phonological component. Share (1995, 1999) argues that there is no convincing evidence to suggest that reading competence can be acquired in the absence of decoding skill. However, decoding is a necessary but not sufficient condition for becoming skilled at word recognition. Proficient reading depends on both phonological and orthographic mechanisms. Therefore, it could be argued that lack of proficiency in one of the component processes encapsulated by the self-teaching model would have detrimental effects on the ability to become skilled in the other, and would in turn have implications for the development of skilled reading.

Whereas some theorists argue that phonological recoding provides opportunities to learn about the orthographic structure of words (e.g., Share's self teaching mechanism 1995, 1999), Ehri (1984; Ehri & Wilce, 1980) provides evidence that there is a reciprocal relationship such that visual information acquired from reading experiences helps develop conceptualisations of the phonemic structure of words and indicates that the acquisition of orthographic images as symbols for sounds underlies both spelling (Ehri, 1980a) and reading (Ehri, 1980b) development. In later formulations of her model, Ehri stresses the importance of developing complete visual-orthographic connections in lexical memory and the importance of phonological recoding in this development. For example, Ehri (1997) notes that sight word reading evolves from connections between graphemes and phonemes based on the alphabetic system, which provides the basis for development of sight word reading. In English, written words consist of fixed sequences of letters that symbolise the pronunciation of specific words. Individual letters or letter combinations equate to symbols for phonemes or phoneme blends. Letters combine in consistent patterns across words to symbolise larger syllabic and subsyllabic units.

There are four phases in Ehri's (1992, 1997) model that reflect the predominant type of connection linking written representations to pronunciation and meaning. In the pre-alphabetic phase, word recognition is based on salient non-alphabetic visual cues rather than letter sound connections. The partial alphabetic phase involves phonetic cue reading where connections are formed between some of the letters in written words and the sounds that are detected when they are pronounced, usually first and final letters (e.g., Ehri & Wilce, 1985). Connections are derived from letter-sound or letter-name knowledge. For example, on hearing the pronunciation of a word, children associate the sounds they hear with the written representations. If they know the letter names, the process can be further enhanced because letter names tend to contain or cue the relevant sound. Only partial connections are made because they cannot segment the words, lack full knowledge of the spelling system, and do not know how to group graphemes. Although this provides a system for remembering words, they can often confuse words with similar letters.

During the full alphabetic phase, readers form complete connections between written representations and phonemes as they can now segment pronunciations of words into phonemes and have knowledge of how graphemes symbolise phonemes in the spelling system. Spellings become fully bonded to pronunciations in memory, resulting in increased word recognition accuracy. In comparison to partial alphabetic readers, full alphabetic readers can decode unfamiliar words. When words become familiar, they become known by sight, which increases the efficiency of word recognition.

The final phase is the consolidated alphabetic phase, which reflects knowledge of the phonological counterparts of multi-letter graphemes or units. Letter patterns become part of generalised knowledge of the spelling system. Being able to represent larger letter units decreases the number of connections needed to secure words in memory and helps in learning multi-syllable words. This phase is also described as cipher reading and this ability usually emerges around Grade 2.

Ehri and Soffer (1999) demonstrated that graphophonemic knowledge is critical to the full alphabetic phase and is consistent with the idea that decoding skills are important for the development of alphabetic knowledge. It involves understanding that letters function as graphemes to symbolise phonemes and learning how to segment the pronunciation of words to detect phonemes. Similarly, Joubert and Lecours (2000) found that their participants required more time to read nonwords containing complex graphemes than nonwords with graphemes corresponding to single letters. They suggested that within the sublexical route there is an independent cognitive process that assembles letters into graphemes, indicating a role for orthographic processes in what is usually considered to be a phonologically driven task.

Goswami (1993) argues that reading acquisition models do not accommodate the evidence regarding the role of analogy use. Given that the use of analogy reflects both orthographic and phonological knowledge, Goswami (1993) describes an interactive analogy model that proposes that the development of reading skills represents an increasingly refined process of lexical analogy. It predicts that beginning readers establish orthographic recognition units with phonological underpinning at the onset-rime level. As phonological knowledge improves, awareness of phonemes develops and phonological coding of smaller grapheme units is established to supplement processing at the onset-rime level. This model also accommodates the development of pronunciation rules as a result of this refinement.

A prevalent argument in the literature is whether use of a GPC strategy (small units first hypothesis) precedes use of use analogy in reading acquisition or vice versa (large units first hypothesis). Goswami and Bryant (1990) concluded from their review of the earlier literature on phonological awareness that awareness of phonemes is more likely to be a consequence of learning to read whereas knowledge of onset-rime divisions is available to beginning readers. For example, a review of the literature on phoneme deletion studies indicated that young children, especially nonreaders, have difficulty detecting and manipulating phonemes (Liberman, Shankweiler, Fischer, & Carter, 1974; Treiman, 1985; Treiman & Baron, 1981), as do adults who have not learned an alphabetic script (Morais, Cary, Alegria, & Bertelson, 1979), although they are relatively accurate at detecting initial and final sounds (Bruce, 1964; Fox & Routh, 1975; Rosner & Simon, 1971). Wise, Olson, and Treiman (1980) provide evidence that placing emphasis on onset-rime units benefits mapping of sound units onto print units needed to learn new words. Although there was evidence that the children in their sample could benefit from subsyllabic units unrelated to the rime, this was to a much lesser extent.

A further empirical study by Goswami and East (2000) confirmed the position that for beginning readers, large units are implicitly specified but they need to be taught about small units. Large units are utilised using analogy but this depends on the size of the child's reading vocabulary. They concluded that both rhymes and phonemes are important to beginning readers and predict a relationship between onset-rime and phoneme level representations. Although Goswami's view has recently been critiqued (e.g., Savage, 2001) she maintains that rhymes are important for learning to read English and cites empirical evidence to support her contentions (Goswami, 2001).

Brown and Deavers (1999) discuss the use of analogy compared to GPC rules in reading 'regular' and 'irregular' nonwords and argue that strategy use depends on the context within which targets are presented. They utilised Coltheart and Leahy's (1992) methodology where nonword pronunciations vary depending on whether participants adopt rime-level or phoneme-level spelling-sound correspondences. Their results supported a small-units first hypothesis as older children were more affected by the consistency of the rime than younger children. Similarly, Coltheart and Leahy (1996a) found that across all skill levels from beginning readers to adult skilled readers, GPC rules were predominantly utilised over body-based analogies for nonword reading.

In contrast, Brown and Deavers (1999) found that both adults and children may exert strategic control over the levels of spelling-to-sound correspondence that they use in reading unfamiliar items. Although younger readers do tend to rely more on GPCs, analogy is facilitated by salient clue words. Analogy is more prevalent for irregular nonwords for better and adult readers compared to younger less skilled readers. More extensive use of an analogy strategy is not made until children are more experienced with print. Similarly, Thompson, Cottrell, and Fletcher-Finn (1996) provide evidence that beginning readers have access to multiple sources of information in the process of reading acquisition including sublexical relationships between phonological and orthographic representations implicitly acquired through exposure to print, acquisition of GPC rules, analogy, and contextual information.

As with models of word recognition, models of reading acquisition highlight the importance of phonological and orthographic processing skills in the development of reading ability. Although it is important to provide an overview of the role of analogy in terms of models of reading acquisition and word recognition given the prevalence of empirical work in the literature, an investigation of analogy theories is not within the scope of this thesis. This thesis is not designed to directly compare the small versus large unit hypotheses of reading acquisition but aims to provide some evidence as to whether less skilled readers have a particular difficulty in utilising small units at the phonemic level compared to normally achieving readers. It also aims to identify whether these readers demonstrate an atypical developmental pattern in their acquisition of these skills and how this impacts on the development of their orthographic processing skills.

Specific Reading Disability: Phonological and Orthographic Processing Skills

As with any cognitive ability, there is a group of children whose reading development falls below what would be expected on the basis of their age. Children may be poor readers for a number of reasons. They may be of low intelligence overall and have difficulty with a number of cognitive tasks. They may have had limited educational opportunities through illness or other factors such as poor family background. They may have a medical problem such as vision or hearing impairment or a neurological deficit that may delay or impair their reading development. For these children, we can identify and account for learning difficulties. However, some children face difficulty in learning to read, even though they have success in the development of other cognitive skills. This kind of impairment cannot be attributed to sensory or neurological damage, lack of educational opportunity, or low intelligence and is described in this context as a specific reading disability (SRD) but is often referred to as dyslexia in the literature. Based on the available evidence, Snowling (1998) concluded that "it seems reasonable to infer that between 4% and 7% of children will have a specific reading disability...equivalent in practical terms to a retardation of some 24 months in reading relative to expectation" (p. 5).

A great body of research has been dedicated to identifying the underlying reason for this deficit in order to assist in diagnosis, remediation, and prevention. Research aims to develop tools for improving diagnosis so that any reading difficulties can be identified as early as possible. Early diagnosis means that children who need extra assistance can be quickly targeted for remediation. With respect to remediation, research aims to identify the core problems that children with an SRD face so that intervention can address the child's specific needs. Furthermore, if we can uncover some factors that are linked to the development of SRD, this will improve the success of early intervention programs designed to prevent later difficulties in reading development. Research in this area also compares children with SRD with children who are normally achieving readers to gain further insight into the normal processes of reading development and word recognition.

Phonological Processing and SRD

Rack et al. (1992) propose that SRDs differ from normally achieving readers with respect to aspects of reading that place heavy demands on phonological processing skills. Nonword reading is a useful way of engaging these processes because they are visually unfamiliar and cannot be accessed directly as they have no orthographic representations in the lexicon. Therefore, it is argued that phonological skills must be utilised to decode nonwords using GPC rules to generate a response. Although it is not a consistent finding (Bruck, 1988; Johnston, Rugg, & Scott, 1988), meta-analytic studies have shown that when SRDs are compared to normal readers, they perform poorly on measures of nonword reading (Rack et al., 1992; van Ijzendoorn & Bus, 1994).

Given that their nonword reading deficit suggests limited spelling-to-sound processing skills, SRDs are also expected to show reduced or absent regularity effects based on dual route conceptualisations of word recognition. Regularity effects are demonstrated by greater speed and accuracy in identifying regular words compared to irregular words. This is based on the premise that irregular words can only be accessed using the orthographic route whereas regular words can also be accessed through the phonological route if the word is unfamiliar and does not have an entry in the mental lexicon. If the phonological route is impaired, an advantage for regular words would not be expected given that recognition of both word types has to rely on the orthographic route. Although Schlapp and Underwood (1988) did not find a regularity effect for poor readers aged between nine and 11 years old on a lexical decision task, there is inconsistent evidence regarding significant differences between SRDs and normally achieving readers for regularity effects. Metsala, Stanovich, and Brown (1998) conducted a meta-analysis to test the prediction of the dual-route version of the phonological-deficit model that regularity effects should be attenuated for individuals with reading disabilities relative to reading level controls. Based on the data from 17 studies, there was no evidence that individuals with reading disabilities demonstrate a smaller regularity effect compared to controls. This suggests that psuedoword reading places greater demands on phonological abilities than reading regular and irregular words.

Computational simulations have revealed that deficient phonological representations can cause a selective deficit in nonword reading yet regularity effects can be preserved (Brown, 1997). Explicit representations at the level of individual graphemes and phonemes led to better performance on nonwords compared to representations based on connections between triplets of letters and phonemes. This suggests that a paucity of phonological representations may underlie a phonological processing deficit. Harm and Seidenberg (1999, 2001) also suggest that the source of phonological dyslexia is impaired phonological representations.

Besides nonword reading, SRDs also show difficulty in other components of phonological processing such as parsing letter strings, segmenting speech into phonemes, and using conversion rules or spelling-to-sound correspondences (Backman, Bruck, Herbert, & Seidenberg, 1984; Fox, 1994; Manis, Szeszulski, Holt, & Graves, 1990; Snowling, 1980). Not only do SRDs demonstrate difficulties in decoding nonwords, this decoding process can be broken down into smaller components to reveal deficits in a number of phonological processing skills.

There is a wide range of tasks that aim to operationalise phonological awareness. Yopp (1988) investigated the reliability and validity of the gamut of tests that had been reported in the literature. Most tests of phonemic awareness were positively correlated. Overall, phoneme deletion tasks were the most difficult whereas rhyming tasks were the easiest. Phoneme blending was easier than phoneme deletion. Two factors were identified; simple phonemic awareness which was represented by segmentation, blending, sound isolation, and phoneme counting, and compound phonemic awareness represented tasks that required multiple steps to complete such as phoneme deletion. A causal link between phonemic awareness and reading acquisition was identified. A similar relationship between reading acquisition and phonemic awareness skills was also reported by Fox and Routh (1984) in their study of segmentation and blending operations.

Perfetti, Beck, Bell, and Hughes (1987) indicated that phonological analysis (segmenting) and phonological synthesis (blending) have different causal relations with reading. Although there is a reciprocal relationship between analysis and reading, phonological synthesis facilitates reading development but there is no reciprocal relationship. This highlights a difference between phonological sensitivity, involving rudimentary recognition of phonological aspects of oral language such as rhyme and alliteration which is sufficient for synthesis tasks, and phonological awareness, involving a more complete awareness of individual phonemes which is sufficient for analysis tasks. However, Wagner, Torgeson, and Rashotte (1994) did not find a distinction between phonological analysis and synthesis to support this distinction between sensitivity and awareness.

Hoien, Lundberg, Stanovich, and Bjaalid (1995) contributed to the debate in the literature as to whether phonological tasks reflect one or several underlying constructs. Based on data from preschool children and replicated with a larger sample of Grade 1 children, they provided evidence that phonological awareness can be separated into discrete rhyme, syllable, and phoneme factors and the phoneme factor accounts for the most variance in reading skill.

Duncan and Johnston (1999) compared phonological awareness at the phonemic and onset-rime level and nonword naming skills of Grade 6 disabled readers and controls to determine which type of awareness is most closely related to nonword naming skill. Only the phoneme deletion task was a correlate of nonword reading. The correlation between these variables for poor readers is consistent with the idea that they have an underlying difficulty manipulating phonology at the phonemic or small-unit level. This is consistent with other findings that have demonstrated that awareness of phonemes and rhymes are separable components of phonological awareness and that segmentation appears to be the more important phonological skill related to reading and spelling acquisition (Muter, 1994; Muter, Hulme, Snowling, &

Taylor, 1998). The study provided support for the phonological deficit hypothesis because the poor readers were significantly worse than reading age matched controls for phoneme deletion and nonword naming and phoneme deletion skill was significantly related to nonword naming ability among poor readers. However, the finding that SRDs have a phonological deficit on phoneme deletion tasks is not consistent as Thompson and Johnson (2000) found that they were less accurate than chronological age match controls but performed similarly to reading age match controls on a phoneme deletion task presented in the auditory modality.

Gottardo, Chiappe, Siegel, and Stanovich (1999) considered whether the processing mechanisms that differentiate skilled from less-skilled readers may be related to the size of the orthographic unit used in decoding. They proposed that less-skilled readers are less efficient as decoding small-unit spelling-sound correspondences compared to decoding larger-unit correspondences. They found that less-skilled Grade 3 readers showed a pseudoword reading deficit on the Woodcock Reading Mastery Test – Revised (WRMT-R; Woodcock, 1987) and on the syllable and phoneme deletion tasks. Overall, less-skilled readers were less sensitive to all measures of spelling-sound correspondence, regardless of unit size. However, the evidence indicated a particular difficulty with small units based on their phoneme deletion performance. Assink, Lam, and Knuijt (1998) also provide evidence that poor readers appear to have inadequate command of grapheme-phoneme associations at the level of individual letter-sound connections.

Therefore, in contrast to earlier research that suggested that awareness of rhyme and alliteration predicts reading and contributes to both reading acquisition and development of sensitivity to phonemes (Goswami & Bryant, 1990), phonological sensitivity, or the ability to analyse, segment, and blend phonemes, has more recently been reported to be more strongly related to word identification and phonological decoding compared to other phonological processing abilities (Bowey, 1996) and syntactic processing and verbal working memory (Gottardo, Stanovich, & Siegel, 1996). In particular, phoneme deletion appears to be the most valid measure of phonological awareness (Lechner, Gerber, & Routh, 1990).

Coltheart (1996) highlighted the need for further research on components of the phonological processing system such as phoneme segmentation, deletion, and synthesis to determine how these phonological processing skills may contribute to the nonword reading deficit typically found in SRDs. Phonological manipulation skills indicate the extent to which a child possesses well specified segmentally structured phonological representations, which are crucial for establishing connections between orthographic and phonological representations (Hatcher & Hulme, 1999). Therefore, this study will utilise measures that index these skills given that they may be more sensitive to group differences in orthographic and phonological processing.

Orthographic Processing and SRD

When SRDs are presented with nonwords or unfamiliar English words, it appears that they cannot rely on their phonological processing mechanism to derive an accurate representation. So, what happens to their orthographic processing skills or ability to access lexical information? Even in the absence of an efficient phonological mechanism, SRDs can develop some word recognition skills depending on the level of exposure to print (Stanovich & West, 1989) and the direct instruction they receive. Most of the research in the area of word recognition has focussed on phonological processing given that there is extensive evidence that this component of word recognition is deficient in SRDs. In contrast, there has been limited research regarding the development of orthographic processes or the nature of orthographic processes in SRD. However, research has indicated that phonological skills are not the only important factor in the development of word recognition skills as orthographic coding has been found to make an independent contribution (Braten, Lie, & Andreassen, 1998; Olson, Wise, Johnson, & Ring, 1997; Stanovich & West, 1989).

Berninger (1994) postulates that one of the reasons that orthography receives little attention in the reading literature is that there is a lack of a well established theory of orthography and its role in reading and writing acquisition. She argues that such a theory must take into account developmental changes in orthographic knowledge and should be integrated with our current understanding of phonological processing. Progress in research on orthographic processing has also been limited due to the lack of consensus regarding how to define, operationalise, and measure it (Olson, Forsberg, Wise, & Rack, 1994; Vellutino, Scanlon, & Tanzman, 1994), largely because orthographic processing involves multiple kinds of orthographic knowledge (Berninger, 1994).

A small body of research has begun to evolve which investigates the use of orthographic codes to access the mental lexicon in normally achieving readers and readers with an SRD (see Olson, Forsberg, & Wise, 1994 for a review). Manis

Szeszulski, Holt, & Graves (1988) designed a test battery to measure the degree of phonological and orthographic strategies in reading, spelling, and associated visual and linguistic skills of SRDs compared to reading age match controls at three grade levels (Grades 1, 2 and 3). For SRDs and controls there was a developmental improvement in phonological and orthographic processing skills with each increment of reading grade level. The performance of SRDs was qualitatively different than reading age match controls as they were poorer at reading and oral language tasks involving phonological information (e.g., nonword pronunciation, phoneme deletion, rhyme generation) and were better at tasks requiring strictly visual processing (e.g., visual matching of letters and shapes) whereas the groups did not differ for orthographic tasks (e.g., lexical verification, lexical decision, homonym matching). This is in contrast to a similar study reported by Manis et al. (1990) in which it was found that, in addition to a difficulty with measures of phonological decoding, SRDs tended to perform at a lower level than both reading age and chronological match controls on the same battery of orthographic tasks.

Olson, Kliegel, Davidson, and Foltz (1985) and Olson, Wise, Conners, Rack, and Fulker (1989) utilised a pseudohomophone choice task, which required SRDs and reading age matched controls to discriminate a real word from a pseudohomophone foil (e.g., rain-rane). In both studies, the groups could not be discriminated in terms of accuracy on this task. However, SRDs had faster reaction times than controls. The superiority of SRDs on this task is not a robust finding. For example, Manis, Custodio, and Szeszulski (1993) used a similar task but found no group differences in a longitudinal study of readers with an SRD and their reading age match controls. Furthermore, Stanovich and Siegel (1994) found that SRDs were deficient on this task compared to reading age match controls. One difficulty with the pseudohomophone choice task is that it may be confounded by spelling ability as it requires knowledge about the spelling of words. However, it was not documented in any of the above research whether the participant's ability to spell the stimulus words was measured. This would be an important consideration for future research using this task.

An alternative orthographic task designed by Siegel, Geva, and Share (1995) measures the ability to discriminate between nonwords containing legal combinations of English letters and those containing letter strings in positions that never occur in the English language. Given that the stimuli in this task are pronounceable non-words, it is not confounded by the ability to read or spell the words. Therefore, this orthographic awareness task may access a more general level of orthographic knowledge than other tasks because it requires an understanding of probable sequences and positions of letters within words. Both Siegel et al. (1995) and Stanovich and Siegel (1994) report that SRDs were superior to reading age match controls on this task, despite the observation that SRDs were deficient on the pseudohomophone choice task in the latter study. Similarly, Pennington, McCabe, Smith, Lefly, Bookman, Kimberling, and Lubs (1986) investigated spelling errors of adult dyslexics and found that they were significantly more accurate on some complex aspects of English orthography compared to spelling age match controls. However, Manis, Doi, and Bhadha (2000) found that Grade 2 participants identified as having a phonemic awareness deficit, based on a sound deletion task, performed similarly to controls on orthographic measures including exception word reading, pseudohomophone choice, and orthographic awareness. However, few participants in the sample were severely disabled as only two participants in the phonological deficit group performed below the 25th percentile.

These studies have provided relatively inconsistent results regarding the nature of orthographic processing in SRD, which may be attributed to the nature of the task. Simultaneous presentation of targets and foils tends to enhance the performance of readers with an SRD. Berninger (1994) suggests that readers with an SRD may have a lower criterion for orthographic precision but are more accurate when target words can be compared to foils. Therefore, these tasks are less likely to discriminate between SRDs and controls.

For beginning and skilled readers, it has been demonstrated that orthographic information is activated during, and interferes with, performance on phoneme awareness tasks such as phoneme counting and phoneme deletion (Barron, 1994; Donnenwerth-Nolan, Tanenhaus, & Seidenberg, 1981; Ehri & Wilce, 1980; Seidenberg & Tanenhaus, 1979; Tunmer & Nesdale, 1982). However, the evidence for the relationship between orthographic and phonological representations in dyslexic readers is less consistent. For example, some studies have shown that dyslexic readers do not use orthographic information to the same extent as normal readers suggesting independence between orthographic and phonological codes (Bruck, 1992; Perin, 1983; Zecker, 1991). In contrast, Rack (1985) suggests that dyslexics rely more on orthographic information than normal readers as they use it to compensate for poor phonological processing. Similarly, Bruck (1992) concluded that with increased reading skills, dyslexics tend to use orthographic information when making phonological judgements and that they potentially rely on orthographic information to a greater extent than normal readers.

Landerl, Frith, and Wimmer (1996) conducted a further investigation of the extent to which orthographic information interferes with the performance of 12-year-old children with dyslexia on phoneme awareness tasks compared to spelling level and age matched controls. For the phoneme counting and phoneme deletion tasks, normal readers were heavily distracted by the knowledge of word spellings but for dyslexics the distraction was less strong as was indicated by dyslexics showing a significantly lower number of orthographic intrusions. However, dyslexic children committed more other errors, demonstrating their difficulty with phoneme segmentation. Therefore, a weak link between phonological and orthographic representations might be a central problem in dyslexia such that seeing a written word does not automatically evoke the word's phonology and vice versa. Leinonen, Muller, Leppanen, Aro, Anonen, and Lyytinen (2001) also provide evidence that phonological and orthographic processes are less highly integrated in adult dyslexic readers.

In their review of the literature on orthographic and phonological processes, Lennox and Siegel (1994) concluded that successful reading depends upon the integration between phonological and orthographic skills. Children with reading disabilities are generally deficient in terms of phonological abilities. In contrast, they are comparable to reading age matched controls on orthographic tasks where word-specific information is required (Olson et al, 1985; Olson et al., 1989) and are superior to reading age match controls on orthographic tasks measuring general knowledge of English orthography (Siegel et al., 1995).

Although these findings suggest that children with reading disabilities are more sensitive to orthographic features than normal readers, it is unclear from the research whether or not this serves as a compensatory mechanism. However, Lennox and Siegel (1994) argue that the cognitive profile of children who have a reading disability may include deficient phonological skills and superior orthographic skills. The conclusion that SRDs are more sensitive to orthographic features than controls is inconsistent with the evidence reported by Landerl et al. (1996) that this population is less sensitive to orthographic information as they experience fewer orthographic intrusions on phoneme awareness tasks. Therefore, this thesis aims to clarify this discrepancy in the literature by investigating the developmental differences between SRDs and normally achieving readers on measures of phonological and orthographic processing skills.

Development of Phonological and Orthographic Processing Skills in SRDs and Normally Achieving Readers

Manis et al. (1993) report a study designed to assess the developmental course of phonological and orthographic skills involved in word recognition and spelling in normal and reading disabled children over a two-year longitudinal study. The performance of the SRDs was compared with chronological and reading age peers. The assessment battery included tasks designed to measure component skills of phonological and orthographic processing. The phonological processing measures included phoneme deletion and pseudoword pronunciation. The phoneme deletion task was designed to examine the ability to analyse spoken nonwords into their individual phonemic elements. The experimenter orally presented nonwords and the participants had to pronounce the nonword without one of the phonemes, for example "sparf" without the /p/ is "sarf". Pseudoword pronunciation measured the ability to translate an orthographic code into a phonological code. Some pseudowords shared common spelling patterns with real words whereas others were chosen so that they did not resemble a common spelling pattern so that pronunciation depended entirely on decoding ability rather than use of analogy. The orthographic processing measures were orthographic verification and homonym verification tasks. The other tasks in the study included pseudoword and irregular word spelling to measure the phonological and orthographic aspects of spelling ability.

The improvement in word identification skills observed for dyslexic readers over the course of the two-year study was largely attributed to improvements in orthographic skill, although their deficit on this measure in relation to normally achieving readers remained reasonably stable over time. Although the dyslexics made gains in phonological processing over time, they demonstrated particular difficulty in relation to pronunciation of nonwords with uncommon spelling patterns, phoneme deletion, and irregular word spelling compared to controls. Manis et al. (1993) concluded that their results were consistent with the popular position that dyslexics have a core deficit with regard to processing speech at the level of the phoneme as they made limited progress on tasks for which it was essential to analyse words at the phonemic level such as phoneme deletion and naming pseudowords with uncommon spelling patterns. Although the finding for irregular word spelling does not appear to be consistent with a phonological deficit hypothesis, it may be the case that SRDs attempt to use a phonological strategy to spell irregular words that are not within their lexicon or they may find it difficult to access the entry in the lexicon if they do not have well established connections between phonological and orthographic representations (Landerl et al., 1996).

Snowling, Goulandris, and Defty (1998) conducted a two-year longitudinal study to investigate whether dyslexia is a disorder of development and whether subtypes of dyslexia exist. The baseline data indicated that, although dyslexic children were generally poorer than chronological age match controls for reading, spelling, and phonological processing skills, their performance was consistent with that of younger reading age matched controls suggesting that the dyslexic readers were delayed on these tasks. However, the longitudinal data indicated that dyslexic readers had an atypical pattern of development as they performed significantly poorer than reading age match controls over time.

Pennington, Lefly, Van Orden, Bookman, and Smith (1987) found that, in a sample of child, adolescent, and adult dyslexic and normally achieving readers from the same family, orthographic learning occurred early whereas phonological processing skills had a more protracted developmental course. Dyslexic readers demonstrated little improvement in phonological skill across age, but made steady improvement on orthographic coding tasks. Differences between dyslexics and reading age match controls on a nonword reading task were found only for adults and not for adolescents. There were no reading age match controls included for the sample of dyslexic children who had a mean age of 9.6, therefore no conclusion can be made regarding a developmental deficit for this age group.

Phonological and Orthographic Processes in Subtype of SRDs

Although it is not within the scope of this thesis to identify subtypes of SRDs, there is some evidence from the subtyping research in the literature that contributes to an understanding of the development of and relationship between phonological and orthographic processes in SRDs. Before outlining that literature, an overview of dyslexic subtypes will be provided.

A number of attempts have been made to classify subtypes of SRD. Coltheart (1985) demonstrated support for his dual route model of word recognition from the pattern of deficits shown by patients who had acquired reading disorders after brain injury. He hypothesised that if two separate procedures existed for reading aloud then he expected to find different subtypes of patients in whom one of the procedures was impaired while the other was intact. There has been some evidence from single case studies of a double dissociation of deficits in brain-injured patients that supports the existence of two separate word recognition processes (Bub, Cancelliere, & Kertesz, 1985; Funnel, 1983). These patients either have a selective impairment in the ability to read pronounceable nonwords and relatively intact ability to read words (phonological dyslexia) or, the nonlexical procedure remains fully intact but the number of words with accessible lexical representations is usually limited to high-frequency words (surface dyslexia).

There are reported cases of developmental dyslexia that mirror the subtypes identified for acquired disorders (Castles & Coltheart, 1996), however the incidence of patterns of reading that are consistent with developmental phonological dyslexia is higher and appears to be more robust than developmental surface dyslexia (Castles &

Coltheart, 1993; Manis et al. 1988, 1990; Stanovich, Siegel, Gottardo, Chiappe, & Sidhu, 1997). For example, Castles and Coltheart (1993) attempted to determine whether patterns of reading can be found in developmental dyslexia that are analogous to those found in acquired dyslexia and are consistent with the dual route model of reading. Using a sample of dyslexics ranging in age from eight to 14 years old and their reading age matched controls, regression analyses were conducted on regular, irregular, and nonword reading accuracy. Evidence was found for a double dissociation between surface and phonological dyslexic reading patterns, although a higher proportion was classified as having phonological dyslexia. However, a large proportion of the dyslexic sample demonstrated difficulties with both irregular and nonword reading, although tended to be markedly worse on one compared to the other. Therefore, although the majority of dyslexics in this sample appeared to have a phonological deficit, a proportion of dyslexic readers who have a primary difficulty with nonword reading, which indexes the operation of the phonological route, also have a secondary difficulty in utilising the orthographic route to read irregular words. This finding suggests that impairment in one route of the dual model can have secondary effects on the functioning of the other route, suggesting some interplay between the development of phonological and orthographic processing skills.

Manis et al. (1988) attempted to classify subtypes of dyslexics based on their strengths and weaknesses on phonological and orthographic tasks. The majority of dyslexics demonstrated a specific phonological processing deficit whereas there were fewer examples of dyslexics showing a difficulty with orthographic strategy use. Although Manis et al. (1988) found that orthographic processing difficulties usually involved deficits regarding speed of access to orthographic information, Manis et al.

(1990) reported that SRDs were also less accurate than both reading age and chronological age match controls on orthographic tasks. These dyslexics appeared to have impaired knowledge of orthographic patterns for specific words and this was usually seen in conjunction with a phonological problem.

Snowling et al. (1998) also investigated whether cognitive differences underlie phonological and surface dyslexia subtypes found in their sample. The findings indicated that individual differences in dyslexia resulted from variation in the severity of phonological processing deficits. SRDs with a specific nonword deficit (phonological dyslexia) had more significant phonological processing difficulties compared to SRDs who had a primary difficulty with decoding irregular words (surface dyslexia) suggesting an atypical pattern of reading development in phonological dyslexia. In contrast, the performance of surface dyslexics on phonological tasks was appropriate for their reading age but lower than expected given their chronological age. This suggests that they although they are delayed, they follow a normal developmental course. Manis, Seidenberg, Stallings, Joanisse, Bailey, Freedman, and Curtin (1999) provide further evidence for a distinction between phonological dyslexia characterised by deficits in nonword reading and phoneme awareness, and delayed dyslexia characterised by difficulties with the development of orthographic skills.

Another relevant finding that emerged from the Manis et al. (1988) study was that some normal readers demonstrated a phonological deficit. Therefore, this suggests that it is possible to make normal progress in reading without a high degree of skill in phonological decoding. However, the fact that SRDs do not make normal progress suggests that they are unable to compensate adequately for their phonological processing difficulties, which may be a result of less precise or incomplete orthographic representations in the lexicon (Manis et al., 1990). Similarly, Lundberg and Hoien (1990) provide evidence that without intact phonological skills, readers cannot develop accurate orthographic representations.

Although SRDs have typically been represented as having a core phonological deficit, the evidence suggesting a subgroup of SRDs who demonstrate an orthographic processing deficit indicates that we cannot always assume that, because a child has been identified as having an SRD, they will need extra instruction in phonological processing skills. However, we must also ask the question of whether it is useful to compartmentalise SRDs into two distinct groups. Coltheart, and Jackson (1998) argue against defining dyslexia with respect to a demonstrated phonological difficulty, and in relation to exclusion criteria such as IQ. They suggest that an alternative method is to evaluate reading subskills against age-related norms to obtain a profile of the child's reading system. This will allow the identification of proximal causes of reading difficulties and will assist in identifying targets for remediation. It may be of more benefit to view SRDs as falling somewhere on a spectrum that ranges from phonological difficulties to orthographic difficulties to account for individual variation in orthographic and phonological skills in SRDs. It is also important to highlight the distinction between the tendency to use a phonological or orthographic strategy and skill in using that strategy. Perhaps it is not the case that SRDs cannot use a particular strategy at all but are less skilled in the use of that process.

Phonological and Orthographic Strategy Use in SRDs and Normally Achieving Readers

Although there is continued debate surrounding the nature of word recognition and reading acquisition models, both phonological and orthographic component processes play a significant role, regardless of the model currently receiving favour. However, results based on previous research are problematic for a number of reasons. For example, an important issue raised by Manis et al. (1993) is that phonological and orthographic skills may be difficult to measure independently because most measures of orthographic skill are contaminated by phonological processing. There are two explanations for this. One is that strong phonological decoding skills are related to rapid acquisition of orthographic codes in memory as proposed by Share's (1995, 1999) self-teaching model. Furthermore, younger and poorer readers tend to find it difficult to avoid using a phonological strategy on orthographic tasks. For example, Bruck (1990) reported that normal readers become less reliant on phonological decoding whereas adult dyslexic readers continue to use this strategy, even though they have poor spelling-sound knowledge. A second issue is that these tasks measure orthographic and phonological processing ability but do not demonstrate whether normal readers and SRDs differ in terms of preferred or dominant strategy use. Thirdly, there is little evidence suggesting that normal readers and SRDs demonstrate differences in the flexible use of phonological and orthographic strategies in response to task demands. Nor is there evidence regarding the development of dominant strategy use and flexible strategy use in SRDs compared to normal readers.

Hendriks and Kolk (1997) attempted to provide direct evidence for strategic influences in developmental dyslexia and made the assumption that even if one route is more efficient than the other, dyslexic children may still utilise the less efficient route. They examined variations in performance of dyslexic readers when they were required to use a speed versus accuracy strategy in performing a word recognition task. When speed was emphasised, they made more word substitutions and exhibited less sounding-out behaviour, which was regarded as similar to the behaviour of phonological dyslexics who tend to rely on the lexical route. When accuracy was emphasised, the opposite occurred, suggesting that they performed like surface dyslexics and relied on the nonlexical route to identify words. This provides evidence that the reading behaviour of dyslexic children can be affected by strategic decisions.

Foorman and Liberman (1989) investigated the extent to which beginning readers use phonological and orthographic strategies and whether strategy use differs between good and poor readers. Participants were asked to read and spell irregular and regular words and complete a visual recognition task. Good readers were expected to demonstrate a regularity effect to indicate their reliance on phonological codes in word recognition whereas poor readers were expected to use analogies in word recognition using visual-orthographic codes. The results did not indicate a dichotomy between strategy use in good and poor readers. Not all good readers processed words phonologically and not all poor readers were deficient in phonological coding. However, the data indicated that good readers were superior in phonological recoding and application of GPC rules. In contrast, they were weaker in visual-orthographic knowledge given that their reading of exception words was less accurate than regular word reading. The poor readers tended to adopt visual over phonological coding strategies and also benefited from visual-orthographic knowledge provided by clue words. Correlations indicated that participants who had developed segmentation skills tended to use a phonological strategy in word recognition.

In an attempt to differentiate between phonological and orthographic strategy use, Stuart (1990) examined the relationship between strategy use, current reading and spelling ability, and earlier phonological awareness skills in nine-year-old children using a consonant deletion task. Words and nonwords were presented aurally and the participants were asked to delete one of three target consonants (/l/, /n/, /s/) that were part of a consonant cluster. The stimuli were designed so that the target response would differ depending on whether an orthographic or phonological strategy was used and all correct responses were real words. For example, participants were given the word 'cast' and were asked to say the word without the /s/. If they responded 'cart', it was inferred that they had used a phonological strategy which emphasised the sounds of the letters when the /s/ sound was removed whereas if they responded 'cat', this indicated the use of an orthographic strategy which emphasised the spelling of the letters when the letter 's' was deleted. Significantly more phonological than orthographic responses were given, especially for nonword stimuli. The pattern of results suggests that there are two strategies available in this task, an orthographic strategy used mainly with words, which may be mediated by the lexical route of the dual route model, and a phonological strategy used for words and nonwords which may be mediated by the sub-lexical route. Good readers and spellers appear to have access to both routes, but tend to use the sub-lexical route with unfamiliar words or nonwords, whereas poor readers and spellers are dependent on the sub-lexical route (Stuart, 1990).

Although Stuart (1990) provides evidence for differences in strategy use in good and poor readers, from a developmental perspective the results are limited in that performance was only measured at one age level. A second difficulty is that the instructions are presented in the auditory modality and require the deletion of a phoneme (e.g., /s/), which may explain the more frequent use of a phonological strategy given that the modality of presentation and the instructions emphasised the phonological properties of the stimuli. Furthermore, this task investigated dominant strategy use but did not assess flexibility in strategy use. Therefore, recent studies in the psychology department at the University of Tasmania have utilised a forced choice grapheme-phoneme deletion task that constrains the use of orthographic and phonological processes independently in a single task (Binns, 1997; Claydon, 1996; Martin, Pratt, & Fraser, 2000). The instructions given to participants indicate which strategy is to be used to complete the task. The instructions specify whether a grapheme (or letter) or a phoneme (or sound) is to be deleted from the word. If an orthographic strategy is required, participants are instructed to delete a grapheme and pronounce the new word based on its spelling or orthography. If a phonological strategy is required, participants are instructed to delete a phoneme and pronounce the new word based on what it sounds like or its phonology.

For example, in the orthographic condition, participants are presented with the word *thought* and are asked to delete the final letter *t* and say what the remaining letters spell (i.e., though). In the phonological condition, participants are presented with the word *thought* and are asked to delete the final sound */t/* and pronounce the sound of the remaining letter string (i.e., thaw). This task also manipulates the modality in which the stimuli are presented to determine the effects of inconsistencies between the type of instruction (orthographic or phonological) and modality on performance. In this design there are two inconsistent combinations, auditory/orthographic and visual/phonological, where the modality of presentation is not congruent with the instructions for strategy use and therefore places greater demands on working memory. For example, a word presented in the auditory modality will be held in the phonological loop in working memory while it is being manipulated. In order to complete the task using the orthographic strategy, the sound of the word has to be ignored and the visual features of the individual letters have to be generated in order to access the new spelling directly from the lexicon. Similarly, to use the phonological strategy for a visually presented word, the spelling of the word has to be ignored and the sound of the word must be generated but cannot be pronounced out loud. Inconsistent conditions add a degree of difficulty to the task and give an indication of flexibility in strategy use, as it is often the case that the mode of presentation will influence choice of strategy, irrespective of instructions.

Claydon (1996) and Binns (1997) utilised the grapheme-phoneme deletion task with normally achieving primary and high school students and demonstrated age related changes in strategy use and control. Accuracy and flexible use of both processes was found to improve with age. Older children tended to utilise the phonological and orthographic strategies with comparable accuracy. In contrast, strategy use of younger readers was influenced by stimulus modality. They were more accurate for the orthographic strategy when the stimuli were presented in the visual modality and were more accurate at using the phonological strategy for auditory stimuli. Pugh, Rexer, and Katz (1994) have also provided evidence for strategic control and flexible use of coding skills in normal readers in the context of a lexical decision task.

Martin et al. (2000) used the grapheme-phoneme deletion task with SRDs and normal readers and found that this adaptation of earlier versions of the deletion task (Bruce, 1964; Rosner & Simon, 1972; Stuart, 1990) provided a useful measure of group differences in phonological and orthographic strategy use and flexibility. Whereas SRDs demonstrated a particular difficulty using the phonological strategy in the auditory modality, their performance using the orthographic strategy was superior to reading age match controls and equivalent to chronological age match controls in the visual modality, a finding that was consistent with previous studies suggesting intact orthographic processing skills (Siegel et al., 1995; Stanovich & Siegel, 1994). Developmentally, the early reliance on phonological processing by the reading age match controls was superseded by the skill and flexibility of the chronological age match controls in both phonological and orthographic strategy use.

Crossed responses, or errors produced by incorrectly applying the opposite strategy to what was required (i.e., generating a response based on the orthography of the word when a phonological response was required and vice versa), were also analysed as a measure of flexible strategy use. Reading age match controls experienced more phonological intrusions in the auditory modality, as evidenced by a greater number of phonological responses compared to controls when they were required to use an orthographic strategy, suggesting that they over rely on a phonological strategy. SRDs did not differ from controls with respect to the number of crossed responses they made when they were required to use the phonological strategy in the visual modality. Therefore, there was little support for the findings of Landerl et al. (1996) that suggested that SRDs were less likely than normal readers to give a response based on orthographic properties when a phonological response was required.

Furthermore, although SRDs were found to have a deficit in phonological processing, they were not more likely than controls to use an orthographic strategy when they were instructed to use a phonological strategy in an attempt to compensate for that deficit.

If we return to models of reading development that highlight the importance of the interaction between phonological and orthographic processes in the development of skilled reading ability, we again return to the question of whether a problem in one of these processes impacts on the development of the other and how this impacts on the development of reading ability as a whole. Given that SRDs are typically identified as having a phonological deficit then, based on Share's (1995, 1999) self-teaching model, it could be hypothesised that SRDs would not become skilled at orthographic processing. Similarly, Ehri (1992, 1997; Ehri & Saltmarsh, 1995) explains that because poor readers are unable to phonologically recode words very accurately or rapidly, this impacts upon their ability to learn to read words by sight as they are only able to form partial and complete connections between letters and sounds. In addition, the analogy model account of reading difficulties suggests that poor phonological skills impede the development of an orthographic lexicon. For poor readers, it is argued that the interaction between orthographic and phonological knowledge is impaired and phonological skills are not used efficiently to analyse orthography and establish orthographic recognition units (Goswami, 1993). These positions are in contrast to Siegel et al.'s (1995) study that suggests that the orthographic processing skills of SRDs remain intact and act as a compensatory mechanism for a phonological deficit.

Following Lennox and Siegel's (1994) conclusions regarding the cognitive profile of SRDs, the current research aims to investigate whether the pattern of reading acquisition over a two-year period for SRDs deviates from normal reading development and reflects intact orthographic processing skills in order to compensate for a phonological deficit. Different age levels will be utilised to account for differences in the developmental course of phonological and orthographic processes. This study will also utilise both reading age and chronological age match controls. A reading level design allows a test of the hypothesis that the performance of SRDs deviates or is qualitatively distinct from what would be expected given their reading age. Although differences between SRDs and chronological age match controls may be a consequence of reduced experience with written language (Backman, Mamen, & Ferguson, 1984), chronological age match controls were included in this study to determine which, if any, component processes are intact or consistent with same age peers.

The current study will utilise the forced choice grapheme-phoneme deletion task to compare the development of SRDs and normal readers given that it controls for the use of both phonological and orthographic strategies. Following Martin et al.'s (2000) results, it is predicted that SRDs will demonstrate a weakness compared to controls for the phonological strategy whereas they are likely to be comparable to controls for the orthographic strategy, particularly for visual stimuli. Furthermore, they are unlikely to make more orthographic responses than controls when a phonological strategy is required (Landerl et al., 1996; Martin et al., 2000).

To complement the deletion task, an addition task will be used to compare phoneme analysis (deletion) and synthesis (addition) abilities. Based on previous research, it is predicted that normal readers will be more accurate for the addition task compared to the deletion task (Yopp, 1988). However, it is unclear from previous research as to whether SRDs will show a similar advantage for the addition task. For example, Berndt, Haendiges, Mitchum, and Wayland (1996) compared phoneme deletion and phoneme addition to determine whether the nonword reading deficit of patients with acquired dyslexia was due to a specific deficit related to the blending operation (addition) or a general problem in manipulating phonemic segments (deletion). Many of the patients (N=11) found the addition task more difficult than the deletion task suggesting that as well as a deficit in manipulating and segmenting words and their constituents, these patients had an even greater deficit in blending a sound with an already existing word body. If the results from acquired dyslexia can be generalised to developmental dyslexia, as Coltheart (1985) suggests, then SRDs are expected to perform more poorly on the addition task compared to the deletion task. However, Wesseling and Reitsma (2000) found that for reading disabled participants, their poor reading did not appear to be related to a deficit in phoneme blending. Furthermore, Perfetti et al. (1997) found that reading development did not facilitate phonological synthesis suggesting that differences in reading ability are unlikely to impact significantly upon addition task accuracy. Therefore, this research suggests that the performance of SRDs on the addition task may be comparable to normally achieving readers.

Previous results suggest that SRDs will have more difficulty with cross modal conditions in the deletion and addition tasks as they will have more difficulty accessing phonological information from a written code and, similarly, with accessing orthographic information from a spoken code (Snowling, 1980; Fox, 1994; Landerl, et al., 1996). For example, Snowling (1980) presented nonwords and asked dyslexics and reading age match controls to identify whether a target stimulus was the same as or different to a recognition stimulus. The modality of both the initial and recognition stimuli was manipulated arriving at four conditions. Snowling (1988) argued that the cross modal conditions required application of GPC rules. When collapsed across reading age, SRDs were significantly less accurate than controls for the visual presentation-auditory recognition condition. This condition was most like reading because it required decoding the visual presentation stimulus into an auditory code in order to make a comparison with an auditory recognition stimulus. Although reading age match controls became more accurate with age, SRDs did not, suggesting that decoding skills did not improve despite the fact that the reading ability of SRDs improved with age. Both groups found the task easiest when both stimuli were presented in the auditory modality. This research suggests that dyslexics and controls differ in their use of phonological codes for visual stimuli but not for auditory stimuli. Given that the phonological deficit observed for SRDs may operate primarily in the process of recoding from print to sound, it is anticipated that SRDs will be less accurate than reading age match controls for the visual/phonological condition but comparable for the auditory/phonological condition, for the addition and deletion tasks.

Speed and accuracy of orthographic and phonological processing will also be measured using an orthographic (pseudohomophone) choice task (Olson et al., 1985, 1989; Manis et al., 1993; Stanovich & Siegel, 1994) and a phonological choice task also utilized by Olson et al. (1985) in which participants will be required to discriminate a pseudohomophone from a nonword foil. While it is anticipated that SRDs will show poorer performance on the phonological choice task given that they are expected to show a general deficit in phonological processing skills, the previous evidence is less than clear in predicting the performance of SRDs on the orthographic choice task. Given that targets and foils are presented simultaneously, it is conceivable that the performance of SRDs on the orthographic choice task will be commensurate with that of reading age peers (Berninger, 1994), particularly if the data are corrected for ability to spell target words.

Based on the argument that SRDs have a phonological deficit with intact orthographic processing skills (Lennox & Siegel, 1994; Siegel et al., 1995), it is predicted that over two year period, SRDs will make fewer gains for phonological processing skills whereas they will demonstrate significant development in orthographic processing skills. However, if the conclusion based on Share's (1995; 1999) model and other supporting evidence is correct (Ehri, 1992; 1997; Goswami, 1993; Ehri & Saltmarsh, 1995), it is plausible that SRDs may make significant gains in orthographic processing but will still be poorer on these measures compared to controls at Time 2 if evidence is found for a phonological processing deficit. Based on previous longitudinal studies, phonological difficulties are expected to persist over a two-year period (Manis et al., 1993; 1999; Snowling et al., 1998).

Method

Participants

The participants ($N = 135$) were selected from five primary schools and two high schools in Southern Tasmania. Given that a large number of students needed to be screened, there were no criteria regarding selection of schools, except that only public schools were included. Of the schools that agreed to participate, five schools were in the top quartile and two schools fell below the median family income for urban areas based on the 1996 census (Australian Bureau of Statistics, 1996).

The Coloured Progressive Matrices (Raven, Court, & Raven, 1990) and the Standard Progressive Matrices (Raven, 1989) were administered to students in Prep to Grade 2 and students in Grades 3 to 7 respectively to screen for nonverbal ability. Students ($N = 894$) were assessed in their classrooms using group administration procedures. Students performing between the 25th and 75th percentile on this measure ($N = 496$) were then individually screened for reading ability using the Word Identification and Word Attack subtests of the Woodcock Reading Mastery Test - Revised (WRMT-R; Woodcock, 1987).

Three groups of SRDs were selected from Grades 3 ($N = 15$), 5 ($N = 15$), and 7 ($N = 15$). SRDs were initially defined as students with average nonverbal ability whose reading ability was at least 24 months below their chronological age based on their WRMT-R Basic Skills Cluster reading age derived from a composite of the Word Attack and Word Identification subtests. Students were excluded if the discrepancy between reading age and chronological age could be attributed to sensory, neurological, or behavioural problems. It was difficult to find sufficient numbers of

Grade 3 students in the screening sample who met the 24-month lag criterion. Therefore, for SRDs in Grade 3, the discrepancy between reading age and chronological age ranged from 21 to 30 months ($M = 24.07$). However, the smaller discrepancies for Grade 3 SRDs were still regarded as meaningful given they were in a younger age group.

SRDs in each grade were matched with 15 reading age match (RAMs) and 15 chronological age matched (CAMs) controls who were all normally achieving readers. Normally achieving readers were defined as students whose WRMT-R Basic Skills Cluster reading age was at or above their chronological age. Students were excluded if their reading age was more than 24 months greater than their chronological age. Where possible, SRDs were matched to same sex controls. The total sample consisted of 66 males and 69 females, indicating that both sexes were evenly represented overall.

The screening process resulted in three cohorts, each consisting of SRDs and their controls. The cohorts were defined by the grade that the SRDs were in during the screening process, Grade 3 (Cohort A), Grade 5 (Cohort B), and Grade 7 (Cohort C). The means and standard deviations for each of the screening variables are shown in Table 1. As can be seen in Table 1, the screening process appears to have been successful in closely matching SRDs to their reading age and chronological age controls at each level of cohort. The discrepancy between reading age and chronological age for SRDs increases with each increment of cohort and this is mirrored by an increasing discrepancy between SRDs and RAMs for chronological age. Although all participants were within the average range of nonverbal ability, it appears that SRDs had lower percentile ranks than controls in each cohort.

Table 1

Means (M) and Standard Deviations (SD) for Progressive Matrices Percentile Ranks (RPM), Reading Age in Months (RA), Chronological Age in Months (CA), and Discrepancy Between Reading Age and Chronological Age in Months (Lag) for SRDs, RAMs, and CAMs in each Cohort

	Cohort A			Cohort B			Cohort C		
	SRD	RAM	CAM	SRD	RAM	CAM	SRD	RAM	CAM
RPM									
M	48.33	60.00	53.33	50.00	58.33	55.00	38.33	46.67	58.33
SD	14.84	15.81	20.85	16.37	22.49	14.02	16.00	20.85	22.49
RA									
M	88.80	88.60	119.60	99.47	99.40	140.00	112.47	112.20	167.07
SD	2.73	4.00	8.95	5.41	5.29	6.63	7.52	7.47	9.49
CA									
M	112.87	82.27	112.33	131.07	90.67	130.87	154.60	103.13	153.93
SD	3.52	2.96	4.72	2.99	5.12	2.61	3.18	6.92	3.81
LAG									
M	-24.07	6.33	7.27	-31.60	8.73	9.13	-42.13	9.07	13.13
SD	2.60	3.77	6.11	5.67	7.14	6.52	7.02	7.54	9.88

To determine whether the participants were appropriately matched for ability, a 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] ANOVA was conducted for the Ravens Coloured and Progressive Matrices percentile ranks (see Appendix A). The only criterion for this measure was that participants were included if they fell within the 25th – 75th percentile range. Although this criterion was met, mean percentile ranks varied significantly across groups, $F(2,126)=4.16$, $MSE=341.27$, $p<.05$. Post hoc Student Newman Keuls (SNK) tests revealed that CAMs ($M = 55.56$) and RAMs ($M=55.00$) were matched on this measure and were ranked significantly higher than SRDs ($M=45.56$) for nonverbal ability.

A 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] ANOVA was conducted for reading age (in months) to ensure that RAMs and SRDs were matched for reading age in all cohorts (see Appendix A). Significant main effects for both cohort, $F(2,126)=249.09$, $MSE=45.24$, $p<.001$, and group, $F(2,126)=586.77$, $MSE=45.24$, $p<.001$, indicated that reading age significantly increased with each level of cohort and that the RAMs and SRDs were correctly matched for reading age but had significantly lower reading ages than CAMs (SNKs). The significant Group x Cohort interaction, $F(4,126)=15.88$, $MSE=45.24$, $p<.001$, indicated that the advantage that CAMs had for reading age compared to RAMs and SRDs increased in magnitude with each increment of cohort (SNKs).

A 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] ANOVA was conducted for chronological age (in months) to ensure that CAMs and SRDs were matched for age in all cohorts (see Appendix A). Main effects for both cohort, $F(2,126)=778.31$, $MSE=17.54$, p<.001, and group, $F(2,126)=1408.88$, $MSE=17.54$, $p<.001$, indicated that age significantly increased with each level of cohort and that the CAMs and SRDs were correctly matched for age and were significantly older than RAMs (SNKs). The significant Group x Cohort interaction, $F(4,126)=30.86$, $MSE=17.54$, $p<.001$, indicated that the magnitude of the age difference between the older participants (SRDs and CAMs) and RAMs increased with each level of cohort (SNKs). This is a predicted consequence of the increasing discrepancy between the chronological age and reading ages of the SRDs across cohorts, which will be illustrated by the discrepancy data discussed below.

A 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] ANOVA was conducted for the average difference in months between reading age and chronological age for each group across cohorts (see Appendix A), primarily to determine the amount of lag demonstrated by SRDs. Overall, the reading age of SRDs was on average 32.6 months below their chronological age ($SD=9.18$) which was a significantly greater discrepancy than that observed for RAMs ($M=8.04$) and CAMs ($M=9.84$), $F(2,126)=601.60$, $MSE=43.09$, $p < .001$ (SNKs). The discrepancy for RAMs and CAMs was in a positive direction with reading age being higher than chronological age. There was no significant difference between RAMs and CAMs on this measure (SNKs). There was also a significant Group x Cohort interaction, $F(4, 126)=14.94$, $MSE=43.09$, $p<.001$. The discrepancy between reading age and chronological age was consistent across cohorts for both RAMs and CAMs. However, the amount of lag significantly increased with each increment of cohort for SRDs (SNKs).

In summary, the above data indicates that the selection criteria were applied accurately in selecting participants for the study, particularly in identifying the control groups. The screening data indicate that the SRDs and RAMs did not differ significantly for reading age and that the SRDs and CAMs did not differ significantly for chronological age at each level of cohort. For SRDs there was a significant discrepancy between reading age and chronological age, which increased in magnitude across cohorts. Overall SRDs had a significantly lower average percentile rank for the nonverbal ability measure. Although this needs to be taken into account, it is not considered to be of great interpretive significance given that all participants were within the average range of ability for this measure.

Materials and Stimuli

In addition to the screening measures described above, the standardised tests utilised in the study included the Passage Comprehension subtest of the WRMT-R, the Listening Comprehension subtest from the Oral and Written Language Scales (Carrow-Woolfolk, 1995), the Coltheart and Leahy (1996b) regular ($N = 30$) and irregular ($N = 30$) word lists, and the Martin and Pratt Nonword Test Form A (Martin & Pratt, 2001).

The stimuli for the grapheme-phoneme addition task consisted of two lists of eight words with two practice items per list. The stimuli were all real words and were selected on the basis that the addition of a single unit would result in two new words that differ in pronunciation depending on whether an orthographic (grapheme addition) or phonological (phoneme addition) strategy was used. For example, for the word 'seat', the orthographic strategy required the participant to add the letter 'w' after the 's' and pronounce what the new word spells ('sweat'). In contrast, the phonological strategy required the participant to add a /w/ sound after the /s/ sound and pronounce what the new word sounded like (/sweet/). Participants were required to demonstrate their use of the orthographic and phonological strategies in the visual and auditory modalities. The use of the two stimulus lists was counterbalanced across the four resulting conditions (see Appendix B). In the visual conditions, the stimuli were typed in the centre of an A5 sheet of paper in 18 point AvantGarde font with landscape orientation and held together in an A5 size ring binder. In the auditory conditions, the experimenter pronounced the stimuli.

For the grapheme-phoneme deletion task, two additional lists of eight words with two practice items were devised. Some of the stimuli were taken from Martin, Pratt, and Fraser (2000) who first reported the use of this task. Words were chosen on the basis that the deletion of a single unit resulted in two new words that differed in pronunciation depending on whether an orthographic (grapheme deletion) or phonological (phoneme deletion) strategy was used. For example, the word 'bread' is pronounced 'bead' if the participant is required to delete the letter 'r' and say what the new word spells (orthographic strategy) whereas it will be pronounced 'bed' if the sound of the word is emphasised and is pronounced by deleting the sound /r/ (phonological strategy). Presentation modality was manipulated as for the addition task resulting in four conditions (see Appendix C), with the stimuli being presented in the same manner as described for that task.

Three computer administered two-alternative forced choice tasks were included in the experimental measures. The tasks involved the presentation of pairs of targets and foils preceded by practice items and the stimuli are presented in Appendix D. The stimuli for the orthographic choice task were 40 pairs of real word targets and pseudohomophone foils whereas the stimuli for the phonological choice task were 40 pairs of pseudohomophone targets and nonword foils. There were six practice items for each task and the stimuli were those used by Olson, Kliegel, Davidson, and Foltz (1985). The stimuli for the orthographic awareness task were taken from Siegel, Geva, and Share (1995) and consisted of 14 pairs of nonword targets containing legal initial or final letter strings and nonword foils containing initial or final letter strings that never occur in the English language in those positions. There were three practice items for this task.

The stimuli in each pair were presented in 30 point Lucida Console font on the horizontal plane on a computer screen with a fixation point appearing in the centre of the screen between stimulus presentations. Participants had 5000ms to respond before the next item was presented with a 500ms inter-stimulus interval. Positive feedback was given on correct trials.

Procedure

During the screening phase, participants were also administered the Coltheart and Leahy (1996b) regular ($N = 30$) and irregular ($N = 30$) word lists but this data was not used for screening purposes. In addition, the raw data from the WRMT-R Word Attack and Word Identification subtests administered during screening was transformed into W scores for later analysis. Following the screening process, data collection for Time 1 commenced. One participant relocated between screening and data collection and could not be appropriately replaced, therefore there were 14 SRDs in the Cohort A sample. For the remaining 134 participants, the following standardised and experimental measures were administered over two approximately

45-minute sessions conducted on an individual basis in a quiet room in the participant's school. The time between testing sessions varied from 20 minutes to several days depending on when individual students could be released from class.

The WRMT-R Passage Comprehension subtest, OWLS Listening Comprehension, and Martin and Pratt Nonword Test were administered according to the standardised instructions provided in the respective manuals. Raw scores were derived from the listening comprehension and nonword tests, whereas W-scores were derived for Passage Comprehension. Where possible, W scores have been utilised as they have been identified as being more appropriate for parametric statistics than age-equivalent scores as they more closely approximate a normal distribution (Alexander & Martin, 2000).

The grapheme-phoneme addition and deletion tasks were administered in counterbalanced order in the same testing session. For the addition task, the order of presentation for the four conditions was also counterbalanced. For each condition, the requirements of the task were demonstrated using two practice items. In the visual conditions, the participants were required to look at the word but not say it and add a letter (grapheme) or a sound (phoneme) depending on whether an orthographic or phonological strategy was required. In the auditory conditions, the participants were asked to listen to a word and think about how it is spelled (orthographic strategy) or how it sounded (phonological strategy) and what it would spell or sound like if a letter or sound was added respectively. The complete instructions for each condition are included in Appendix E. The number of correct and crossed responses was collated for each condition. Crossed responses were errors produced by applying the incorrect strategy to the task.

For the grapheme-phoneme deletion task, the instructions were essentially the same as those described for the addition task, except that participants were required to delete an item rather than add, and are provided in detail in Appendix F. In the deletion task the phonological instructions required the participant to delete a sound from the stimulus word and pronounce the sound of the remaining word. In the orthographic task, the instructions required the participant to say what the word spelled if a letter was deleted. The four conditions were presented in counterbalanced order and the number of correct and crossed responses was collated for each one.

For the phonological choice task, participants were presented with 40 pairs of pseudohomophone targets and nonword foils and were required to identify the pseudohomophone. In the orthographic choice task, participants were presented with 40 pairs of real word targets and pseudohomophone foils and were required to identify the real word. Participants identified the target by computer key press. If they wished to choose the item on the left of the screen they pressed the 'z' key whereas if they wanted to select the item on the right they pressed the "?" key. The tasks were presented in counterbalanced order. The instructions for these tasks are presented in Appendix G. Accuracy and reaction time data was collated for each task. Given that performance on the orthographic choice task may be affected by the ability to spell the target words, participants were given a written spelling test for target items at the end of data collection.

A second series of data collection was conducted approximately two years after Time 1 for the 98 participants who agreed to remain in the study. The average delay between Time 1 and Time 2 data collection periods was 25.01 months (*SD*=2.96). Table 2 shows the mean delay for each group across cohorts. To determine whether the delay was consistent for SRDs, RAMs, and CAMs in each cohort, a 3[Group: SRD, RAM, CAM] x 3[Cohort: 1, 2, 3] ANOVA was conducted for the mean delay between data collection periods (see Appendix H).

Table 2

Means (M) and Standard Deviations (SD) for the Delay in Months Between Time 1 and Time 2 Data Collection for SRDs, RAMs, and CAMs in each Cohort

	Cohort A	Cohort B	Cohort C
SRD			
M	24.22	27.45	24.20
SD	0.83	3.56	3.46
RAM			
M	24.83	24.42	24.25
SD	1.11	1.08	3.49
CAM			
M	24.70	28.40	23.00
SD	0.82	4.55	0.60

The Group x Cohort interaction was significant, $F(4,89)=3.59$, $MSE=6.71$, $p<.01$, and post hoc tests revealed that the groups were evenly matched in Cohorts A and C. However, in Cohort B, SRDs and CAMs had a significantly larger delay than RAMs

(SNKs). The SRDs and CAMs in this cohort had a longer interval between testing periods because at Time 1 they were in Grade 5 whereas at Time 2, they had moved on to a diverse range of high schools. The process of finding participants at their new schools, obtaining permission, and coordinating data collection at an increased number of schools has contributed to this effect.

Apart from the nonverbal ability measures, all the measures described above were repeated at Time 2. In addition, an orthographic awareness task was included to investigate differences in orthographic knowledge. This task followed the same stimulus presentation and procedures described above for the phonological and orthographic choice tasks. However, in this task there were three practice items and fourteen pairs of nonword targets containing legal letter strings and nonword foils containing initial or final letter pairs that never occur in the English language in those positions. Participants were asked to identify the nonword that could be or looks most like a word to identify their knowledge of legal letter combinations in English orthography (see Appendix G).

Design and Data Analysis

The basic design for this study was a 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] x 2(Time: 1,2) mixed design. Other variables were incorporated into the design depending on the task demands and the specific analyses will be reported in the results section. Only the data for participants who continued for the duration of the study were analysed given that the study adopted a longitudinal design. The data were analysed using mixed ANOVAs (see Appendix I) followed by planned comparisons to clarify the direction of significant effects involving between groups and repeated measures. Student Newman Keuls tests (SNKs) were also used post hoc for effects involving either between groups factors or repeated measures where appropriate. A 5% level of significance was adopted.

Results: Reading Data

Word Identification and Word Attack W scores

Although the WRMT-R Basic Skills Cluster, which comprises the Word Identification and Word Attack subtests, was used to screen participants for reading ability, individual subtest data was collected longitudinally to investigate the development of word identification and word attack abilities of SRDs compared to controls. Therefore, what is of interest is the change in task performance over time for SRDs compared to controls and whether developmental differences depended on age, as represented by the cohort factor. This was investigated using a 3[Group: SRD, RAM, CAM] x 3[Cohort: A,B,C] x 2(Time: 1,2) x 2(Task: Word Identification, Word Attack) mixed ANOVA on the W scores for each task.

The Group x Time x Task interaction was significant, $F(2,89)=9.86$, $MSE=49.94$, $p<.001$, and is illustrated in Figure 1. Planned comparisons were used post hoc to aid interpretation. CAMs had significantly higher W scores than SRDs for both tasks over time and, as a group, made comparatively greater improvement for word identification compared to word attack. Compared to SRDs, RAMs had significantly higher W scores for word attack across time. This provides support for the phonological deficit hypothesis of SRD that would predict poor nonword reading performance (Rack et al., 1992) and demonstrates that this deficit is stable over time. In contrast, SRDs had significantly higher word identification scores than RAMs at Time 1 whereas by Time 2 RAMs had significantly surpassed the SRDs on this measure. SRDs did not improve to the same extent as RAMs for word identification and the data at Time 2 indicates a discrepancy on this task compared to both reading age and chronological age peers. Planned comparisons also revealed that all groups significantly improved over time for both tasks. Group differences in task performance over time did not vary significantly with cohort, $F(4,89)=1.08$, $MSE=49.94$, $p>.05$.

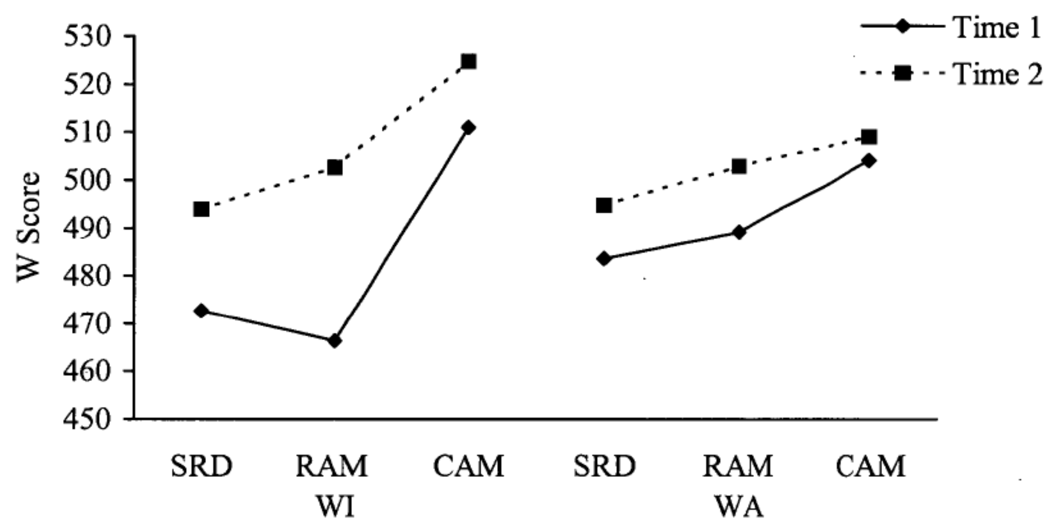

Figure 1. Changes in group means over time for word identification (WI) and word attack (WA) W scores.

Martin and Pratt Nonword Test Raw Scores

To investigate developmental differences in nonword skills over time, a 3[Group: SRD, RAM, CAM] x 3[Cohort: A,B,C] x 2(Time: 1,2) mixed ANOVA was performed on the Martin and Pratt Nonword Test raw scores. The significant main effect for group, $F(2,89)=66.16$, $MSE=80.72$, $p<.001$, was followed by SNKs which indicated that CAMs (M=43.14) had higher raw scores than RAMs (M=32.99) who in turn had higher raw scores than SRDs (M=24.56). This provides further evidence for a specific phonological processing deficit for SRDs given that they were significantly less accurate than both RAMs and CAMs for nonword reading. The significant Group x Time interaction, $F(2,89)=16.48$, $MSE=15.56$, $p<.001$, shown in Figure 2 and followed by planned comparisons indicated that while all groups significantly improved over time, the magnitude of this improvement was greater for RAMs than CAMs and SRDs. Group differences over time did not vary significantly with cohort, *F*(4,89)=0.34, *MSE*=15.56, *p*>.05.

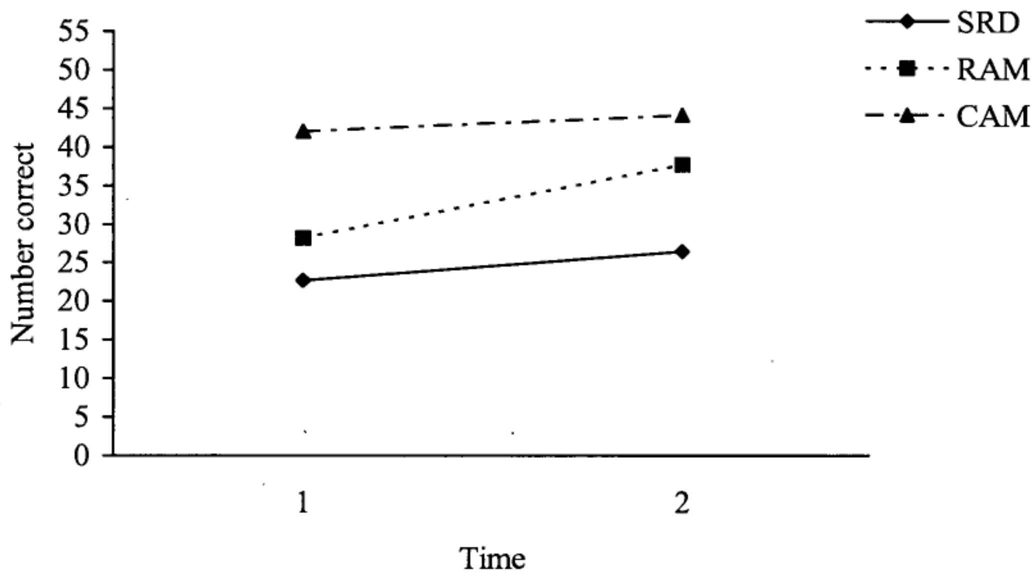

Figure 2. Changes in nonword reading accuracy over time for SRDs compared to RAMS and CAMs.

Coltheart and Leahy (1996b) Regular and Irregular Words Number Correct

To investigate whether there were any significant group differences in the regularity effect over time, a 3[Group: SRD, RAM, CAM] x 3[Cohort: A,B,C] x 2(Time: 1,2) x 2(Task: Regular, Irregular) mixed ANOVA was conducted on the number of items correct for Coltheart and Leahy (1996b) regular and irregular word reading. A direct comparison between irregular and regular word reading was considered appropriate as the items were matched for word frequency, number of letters, and number of syllables (Coltheart & Leahy, 1996b).

Consistent with expectations that there would be a regularity effect, participants were significantly more accurate for regular words (*M*=26.70) than for irregular words (*M*=22.03), *F*(1,88)=324.94, *MSE*=6.40, *p*<.001. The significant Group x Task interaction shown in Figure 3, *F*(2,88)=6.54, *MSE*=6.40, *p*<.001, indicates that the magnitude of the task difference was larger for SRDs and RAMs compared to CAMs. However, the results for CAMs seem to indicate a ceiling effect given that more than 50% of CAMs scored 27 out of 30 or better for both regular and irregular words. Similarly, SRDs performed with high levels of accuracy for regular words only. As can be seen in Figure 3, SRDs had higher mean scores than RAMs for both tasks, particularly for regular words, but planned comparisons revealed that these differences were not statistically significant. SRDs performed significantly poorer than CAMs for both regular and irregular words. There was no evidence that SRDs had a reduced or absent regularity effect compared to controls and this effect did not vary significantly over time, *F*(2,88)=2.12, *MSE*=2.47, *p*>.05.

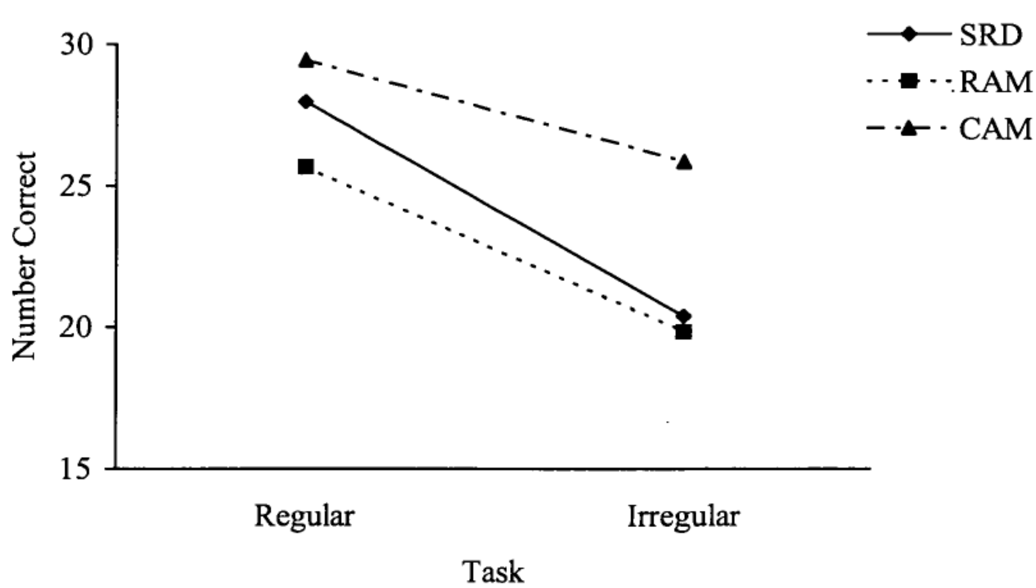

Figure 3. Group differences observed for Coltheart and Leahy (1996b) regular and irregular word reading accuracy.

Passage Comprehension W scores

To investigate developmental differences in passage comprehension skills over Time, a 3[Group: SRD, RAM, CAM] x 3[Cohort: A,B,C] x 2(Time: 1,2) mixed ANOVA was performed on the WRMT-R Passage Comprehension subtest W scores. The overall means for this measure are illustrated in Figure 4. Overall, there was significant improvement from Time 1 (M=491.96) to Time 2 (M=505.36), $F(1,87)=241.55$, $MSE=35.24$, $p<.001$. There was a significant overall main effect for group, $F(2,87)=50.03$, $MSE=135.70$, $p<.001$, with CAMs (M=510.17) having higher W scores than SRDs (M=495.53) who in turn had higher W scores than RAMs (M=490.27) (SNKs).

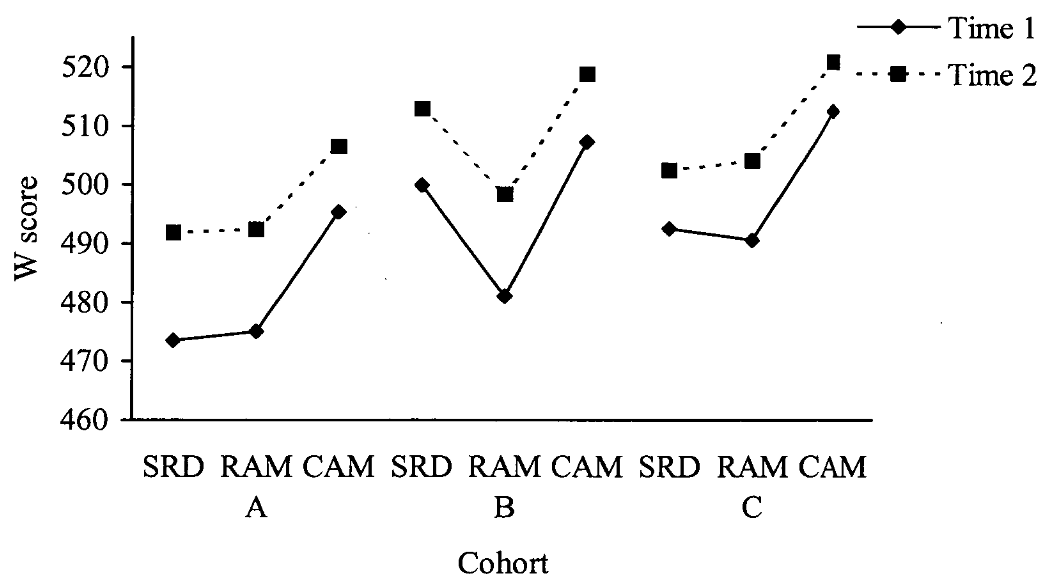

Figure 4. Changes over time for passage comprehension W scores for SRDs compared to controls at each level of cohort.

The significant Group x Cohort interaction, $F(4,87)=4.21$, $MSE=135.70$, $p<.01$, indicated that the advantage that SRDs had over RAMs was significant only for Cohort B (SNKs). Although there were significant differences between SRDs and

CAMs at each cohort, SRDs performed at a level consistent with (Cohorts A and C) or superior to (Cohort B) what would be expected given their reading age.

Group differences also varied significantly across time, $F(2,87)=3.77$, $MSE=35.24$, $p<.05$. Planned comparisons between SRDs and controls at Time 1 and Time 2 revealed that group differences at Time 1 were consistent with the overall pattern described for the group main effect. At Time 2, there was a nonsignificant trend for SRDs to have higher W scores than RAMs ($p = .07$). However, this affect appears to be specific to Cohort B as can be seen in Figure 4, although the Group x Cohort x Time interaction did not approach significance, $F(4,87)=0.46$, $MSE=35.24$, $p>.05$.

Listening Comprehension Raw Scores

To investigate developmental differences in listening comprehension skills over Time, a 3[Group: SRD, RAM, CAM] x 3[Cohort: A,B,C] x 2(Time: 1,2) mixed ANOVA was performed on OWLS Listening Comprehension raw scores. Performance improved significantly from Time 1 ($M=65.73$) to Time 2 ($M=76.99$), $F(1,87)=141.37$, $MSE=42.50$, $p<.001$. There was a significant main effect for group, $F(2,87)=28.70$, $MSE=145.43$, $p<.001$, and SNKs indicated that CAMs ($M=78.23$) had significantly higher raw scores than SRDs ($M=73.19$) who in turn had significantly higher raw scores than RAMs ($M=62.66$). There was a significant Group x Time interaction, $F(2,87)=3.38$, $MSE=42.50$, $p<.05$, and this is illustrated in Figure 5. As can be seen in Figure 5, CAMs had consistently higher raw scores than SRDs and planned comparisons revealed that although this difference was not significant at Time 1 ($p = .10$), it was significant at Time 2. The difference between SRDs and RAMs was significant at both Time 1 and Time 2. This indicates that the listening comprehension skills of SRDs were superior than what would be predicted given their reading age but they were poorer than chronological age peers on this measure, particularly at Time 2. Group differences in development over time were not significantly affected by cohort, $F(4.87)=1.39$, $MSE=42.50$, $p>.05$.

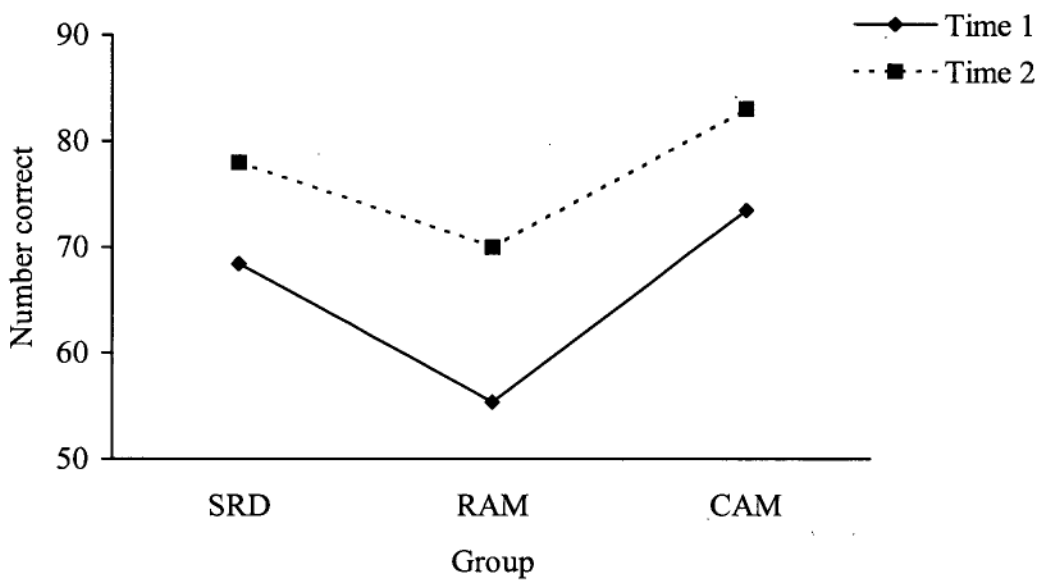

Figure 5. Developmental changes in listening comprehension accuracy over time for SRDs compared to controls.

Results: Grapheme-Phoneme Addition and Deletion

Task differences

Following Berndt et al. (1996), it was hypothesised that SRDs would have more difficulty with blending a sound with an already existing word body (addition) than manipulating and segmenting words and their constituents (deletion). To evaluate this hypothesis, a 3[Group: SRD, RAM, CAM) x 3[Cohort: A,B,C] x 2(Time: 1,2) x 2(Task: Addition, Deletion) x 2(Presentation Modality: Auditory, Visual) x 2(Strategy: Orthographic, Phonological) mixed ANOVA was conducted for the number of correct responses. Only the results pertinent to this hypothesis will be reported.

There was a significant overall main effect for task, $F(1,89)=15.60$, $MSE=2.54$, $p<.001$, with greater accuracy for the addition task ($M=5.21$) than the deletion task ($M=4.89$). The Group x Task x Modality interaction was significant, $F(2,89)=4.84$, $MSE=1.93$, $p<.02$, and is illustrated in Figure 6. This indicated that, for each group, task differences varied depending upon modality of presentation. Planned comparisons revealed that SRDs were significantly more accurate for the addition task, irrespective of modality. In contrast, RAMs were significantly more accurate on the addition task for auditory stimuli only as planned comparisons revealed no significant task difference for visual stimuli. Therefore, it appears that for RAMs, the addition task is more difficult when they have to manipulate visual stimuli. Planned comparisons also revealed that the task differences observed for CAMs were not significant.

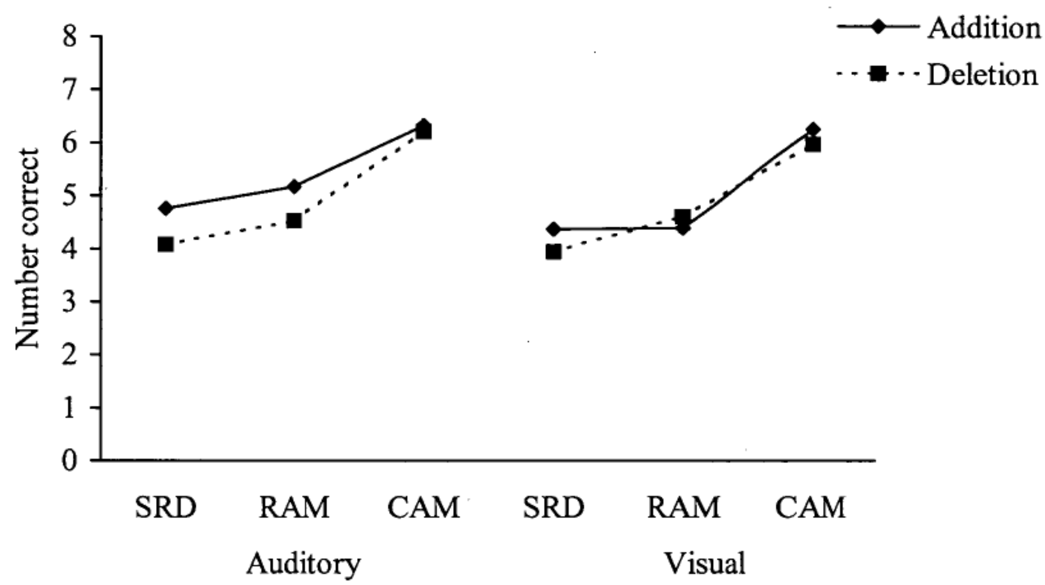

Figure 6. Group differences in addition and deletion task accuracy for auditory and visual stimuli.

Task differences for each group also varied significantly depending on whether a phonological or orthographic strategy was required, $F(2,89)=3.65$, $MSE=2.69$, $p<.05$. As can be seen in Figure 7, SRDs appear to have a particular difficulty in accurately deleting a phoneme from a word. Planned comparisons confirmed that for SRDs, there was no significant difference in task accuracy for the orthographic strategy whereas for the phonological strategy, they were more accurate at phoneme addition than phoneme deletion. In contrast, planned comparisons revealed that both RAMs and CAMs were significantly more accurate at performing the addition task when an orthographic strategy was required whereas there were no significant task differences for phonological strategy use. Therefore, for RAMs and CAMs, it was easier to manipulate the orthography of a word when they were required to add a letter compared to when they were required to delete a letter from a word.

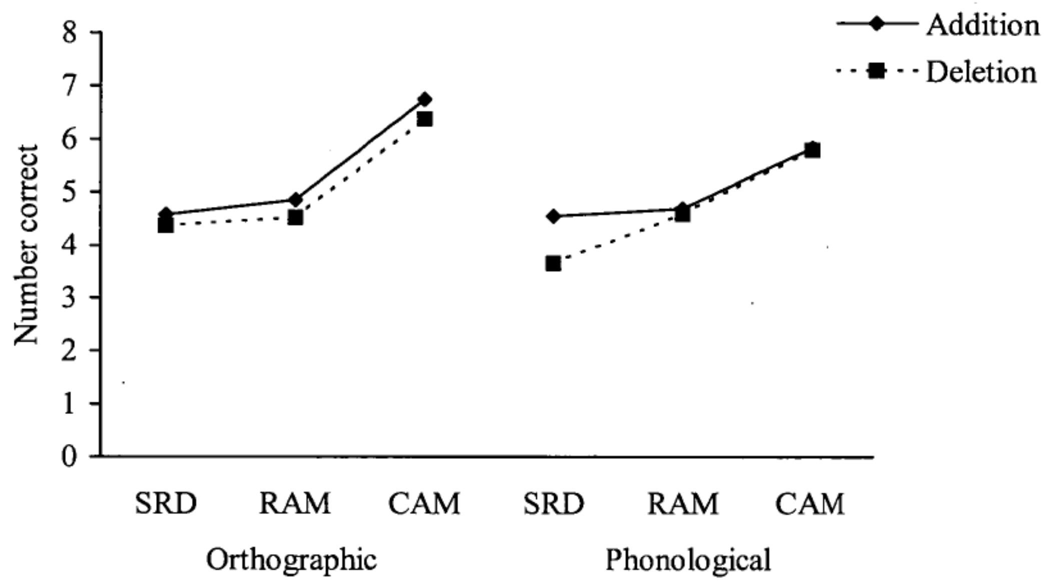

Figure 7. Group differences in strategy use for the addition and deletion tasks.

Addition Task

A 3[Group: SRD, RAM, CAM) x 3[Cohort: A,B,C] x 2(Time: 1,2) x 2(Presentation Modality: Auditory, Visual) x 2(Strategy: Orthographic, Phonological) mixed ANOVA was conducted for the number of correct responses on the addition task. The significant Presentation Modality x Strategy interaction, $F(1,89) = 89.59$, $MSE = 2.00$, $p < .001$, indicated that for auditory stimuli, performance was more accurate for the phonological strategy whereas for visual stimuli, performance was more accurate for the orthographic response strategy (SNKs). These results are illustrated Figure 8 and are in the predicted direction with consistent tasks resulting in greater accuracy than inconsistent tasks, although the magnitude of this effect appears to be greater for visual stimuli. Post hoc tests (SNKs) revealed that performance was comparable for consistent tasks, whereas for inconsistent tasks, the auditory/orthographic condition resulted in greater accuracy than the visual/phonological condition suggesting that it was easier for participants to manipulate an auditory code into a visual one compared to converting a visual letter string into a phonological code.

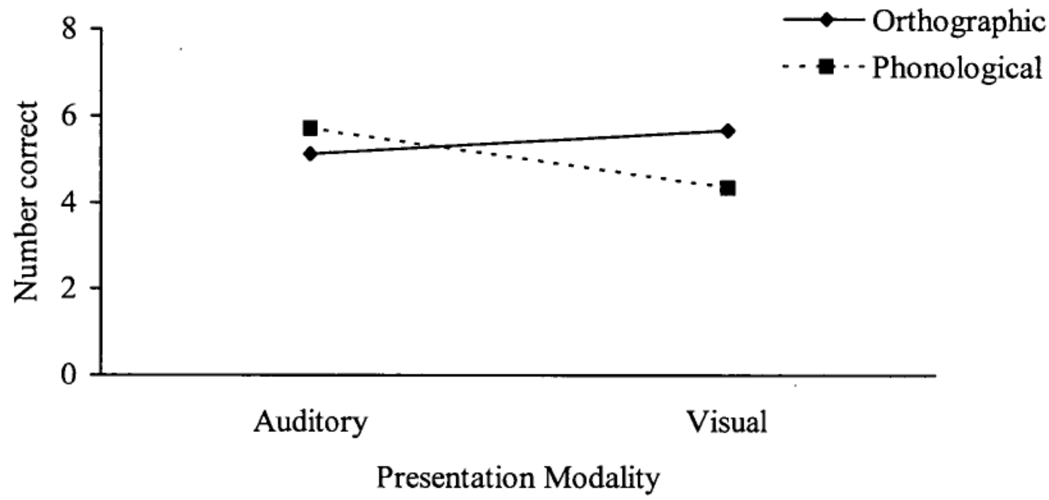

Figure 8. Differences in phonological and orthographic strategy use for the addition task depending on modality of presentation.

This interaction also varied significantly across time, $F(1,89)=11.31$, $MSE=1.47$, $p<.01$, and this effect is illustrated in Figure 9. As can be seen in Figure 9, at Time 2 there was no significant difference in accuracy across strategy types for the auditory stimuli (SNKs). In addition, differences between consistent tasks were found to vary with time because participants were most accurate for the auditory/phonological condition at Time 1, whereas at Time 2, they were most accurate for the visual/orthographic condition (SNKs). Performance improved significantly over time for all conditions except auditory/phonological (SNKs).

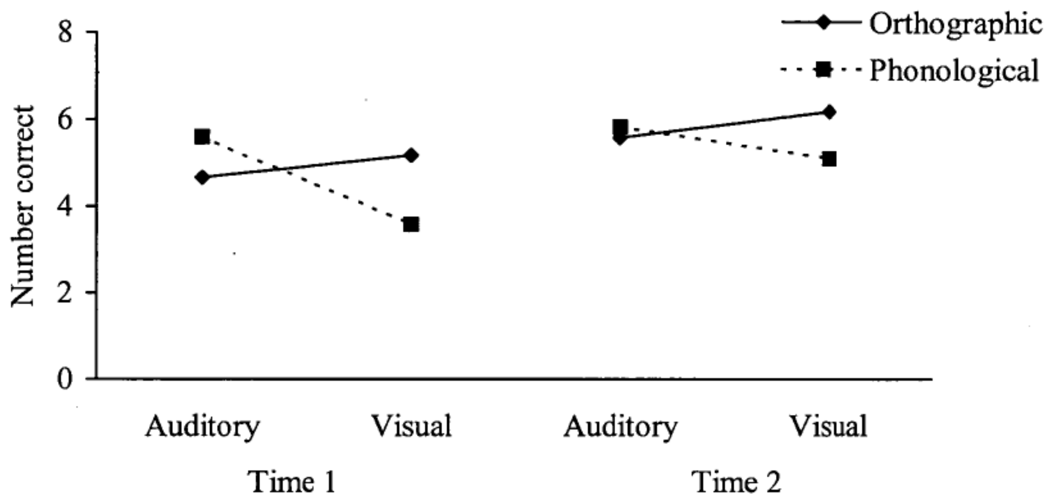

Figure 9. Changes over time for phonological and orthographic strategy use on the addition task depending on stimulus modality.

The Presentation Modality x Strategy interaction also varied significantly across group, $F(2,89)=3.86$, $MSE=2.00$, $p<.05$, and this effect is illustrated in Figure 10. As can be seen in Figure 10, the interaction can be attributed to the auditory presentation stimuli. Although RAMs were more accurate than SRDs for both strategies in the auditory modality, planned comparisons revealed that these differences were not significant. CAMs were significantly more accurate than SRDs and RAMs for the orthographic strategy. Both RAMs and SRDs were significantly more accurate for the phonological response strategy compared to the orthographic strategy for auditory stimuli whereas for CAMs there was no significant difference in strategy accuracy. This indicates that CAMs illustrated greater flexibility in applying the appropriate strategy for auditory stimuli whereas the performance of SRDs and RAMs was facilitated by the effect of consistency. However, ceiling effects may confound the results for CAMs as they tended to demonstrate high levels of accuracy, particularly for the orthographic strategy. Although SRDs were expected to be significantly less accurate than CAMs and RAMs for the auditory/phonological task providing support for the phonological deficit hypothesis, there were no significant group differences for this condition.

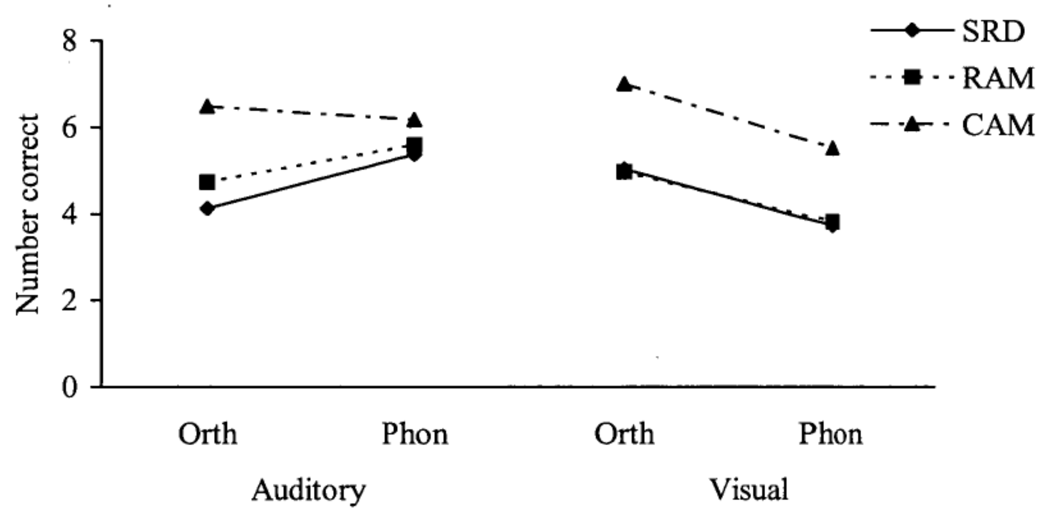

Figure 10. Group differences in strategy use on the addition task depending on modality of stimulus presentation.

The significant Group x Time x Strategy interaction, $F(2,89)=5.42$, $MSE=2.66$, $p<.01$, is shown in Figure 11. Although it appears that all groups improve over time for the phonological strategy, planned comparisons revealed that only RAMs and CAMs significantly improved. Furthermore, SRDs were significantly less accurate than CAMs but did not differ significantly from RAMs at Time 1 and Time 2. For the orthographic strategy, planned comparisons revealed that SRDs and RAMs demonstrated a significant increase in accuracy over time for the orthographic strategy whereas performance appears to have attenuated for CAMs as they did not improve significantly over time. The lack of improvement over time for CAMs is likely to be due to ceiling effects as can be seen in Figure 11. Planned comparisons also revealed that SRDs and RAMs performed similarly at Time 1 whereas at Time

2, RAMs were significantly more accurate than SRDs. Therefore, although SRDs improved significantly for orthographic strategy use over time, they did not improve to the same degree as RAMs. However, SRDs did not improve significantly over time for the phonological strategy even though their level of accuracy was consistent with RAMs at both Time 1 and Time 2.

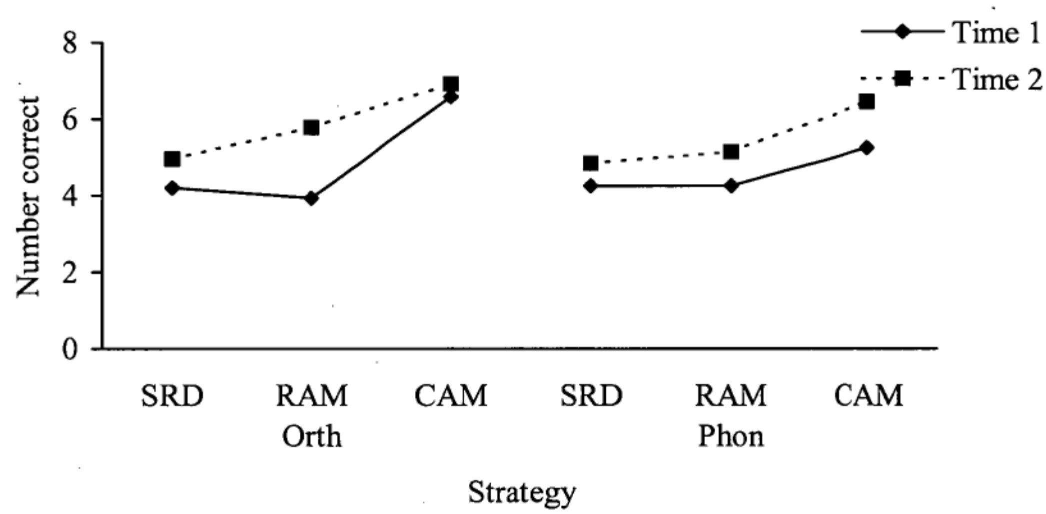

Figure 11. Developmental changes in strategy use over time for SRDs compared to controls for the addition task.

This interaction was also used to identify whether there were any differences in strategy use over time for each group. SRDs did not demonstrate a significant advantage for either strategy at Time 1 or Time 2. RAMs did not show a significant task difference at Time 1 or Time 2, although they tended to be more accurate for the orthographic strategy at Time 2 ($p = .08$). CAMs were significantly more accurate for the orthographic strategy at Time 1 whereas at Time 2 there was not a significant task difference.

In contrast to expectations, the results for the addition task did not provide significant support for the hypothesis that SRDs would show a deficit in utilising a phonological strategy compared to controls. Consistent with the prediction of a phonological processing deficit, SRDs did not show any improvement for phonological strategy use over time compared to controls. However, SRDs did not demonstrate an advantage for a particular strategy over Time. At Time 2, SRDs appeared to have a particular difficulty in utilising an orthographic strategy to complete the addition task as they were significantly less accurate than both RAMs and CAMs. However, when the effect of time was removed and presentation modality was taken into account, SRDs performed at a level that is commensurate with their reading age peers for both conditions involving the orthographic strategy. Group differences did not vary significantly with cohort for any of the interactions involving group.

Deletion Task

A 3[Group: SRD, RAM, CAM) x 3[Cohort: A,B,C] x 2(Time: 1,2) x 2(Presentation: Auditory, Visual) x 2(Strategy: Orthographic, Phonological) mixed ANOVA was conducted for the number of correct responses on the deletion task. The group main effect was significant, $F(2,89)=40.11$, $MSE=7.28$, $p<.001$, and SNKs revealed that overall, CAMs ($M=6.10$) were significantly more accurate than RAMs ($M=4.57$) who in turn were significantly more accurate than SRDs ($M=4.01$). However, the significant Group x Time interaction, $F(2,89)=6.81$, $MSE=3.19$, $p<.01$, followed by planned comparisons revealed that the difference between RAMs and SRDs was significant at Time 2 only. This result is consistent with the Group x Time interaction reported for the addition task accuracy in the previous section.

Accuracy for strategy use varied with presentation modality as performance was more accurate when the strategy required was consistent with the modality of presentation, $F(1,89)=273.43$, $MSE=1.80$, $p<.001$ (SNKs). This effect is illustrated in Figure 12. For consistent conditions, participants were significantly more flexible in applying an orthographic strategy to auditory stimuli compared to utilising a phonological strategy for visual stimuli. For inconsistent conditions, participants were also significantly more accurate at utilising the orthographic strategy, as was found for the addition task.

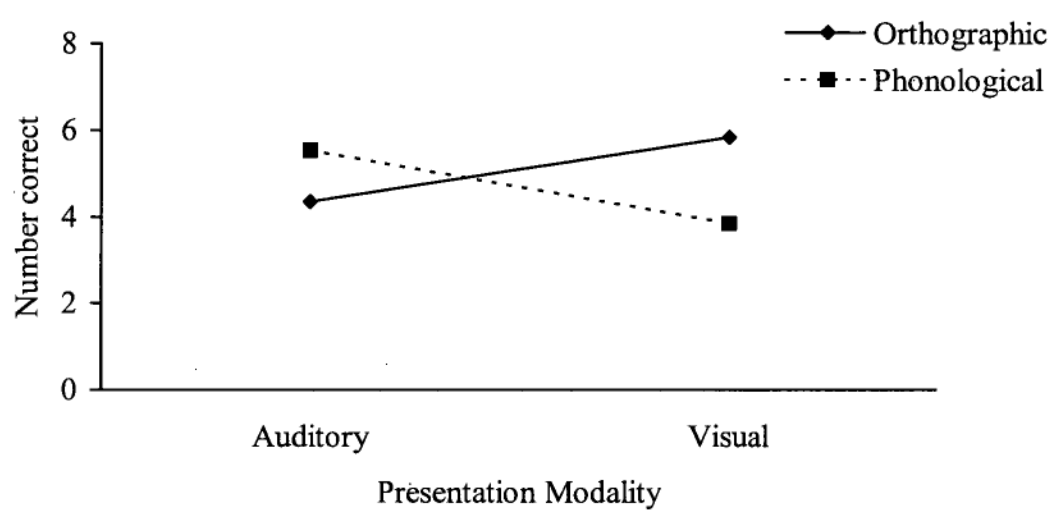

Figure 12. Differences in mean deletion task accuracy for orthographic and phonological strategy use depending on stimulus modality.

Group differences varied significantly with strategy and presentation modality, $F(2,89)=9.23$, $MSE=1.80$, $p<.001$. As can be seen in Figure 13, the advantage that RAMs had over SRDs appeared to be more evident for the phonological strategy. Planned comparisons revealed that SRDs were significantly less accurate than RAMs for conditions involving phonological instructions, whereas they were comparable to RAMs when the task required an orthographic strategy. This provides evidence for a specific phonological deficit given that SRDs were poorer on these tasks than controls. However, for orthographic strategy use, they were consistently less accurate than CAMs but performed at a level consistent with their reading age.

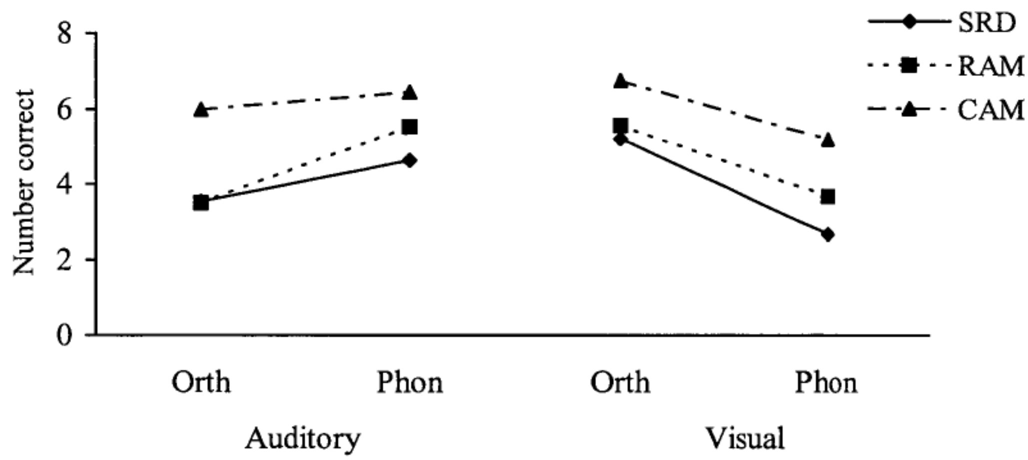

Figure 13. Group differences in deletion task accuracy for orthographic and phonological strategy use depending on stimulus modality.

This interaction was also found to vary with time, $F(2,89)=3.43$, $MSE=1.18$, $p<.05$. This interaction is illustrated in Figures 14 and 15 which show the Group x Presentation Modality x Strategy means at Time 1 and Time 2 respectively. At Time 1, planned comparisons revealed that SRDs were consistently less accurate than CAMs for all conditions. Although SRDs appear to have an advantage over RAMs for the auditory/orthographic condition, planned comparisons revealed that this difference did not approach significance. Similarly, the advantage that RAMs appear to have over SRDs for the auditory/phonological condition was not significant. Therefore, at Time 1 SRDs performed at a level commensurate with their reading age but were significantly less accurate than chronological age peers for all conditions.

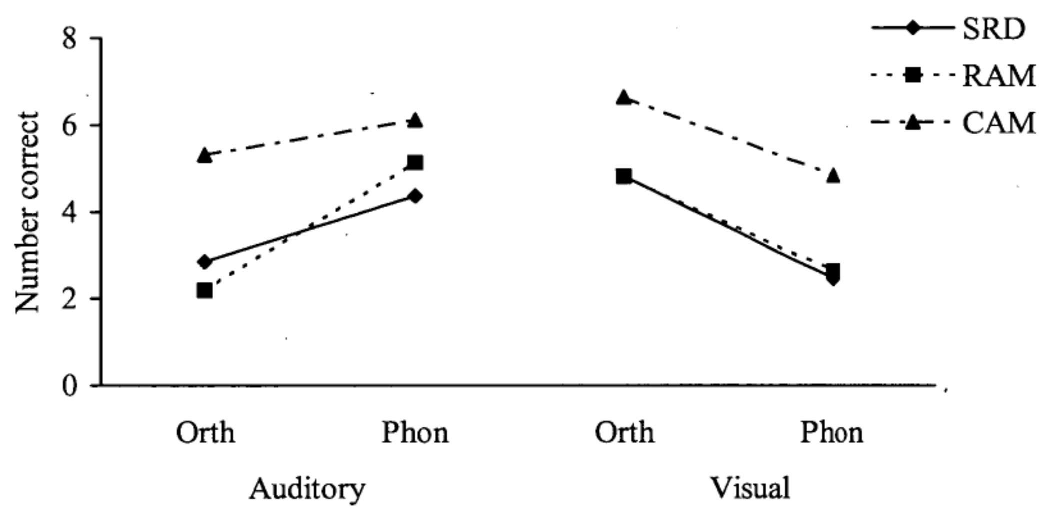

Figure 14. Group differences in deletion task accuracy at Time 1 for orthographic and phonological strategy use depending on stimulus modality.

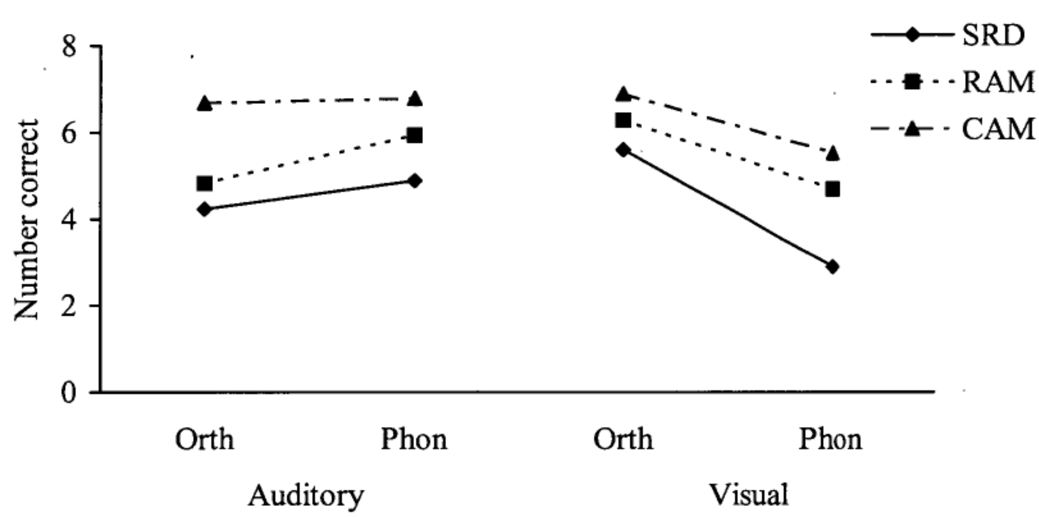

Figure 15. Group differences in deletion task accuracy at Time 2 for orthographic and phonological strategy use depending on stimulus modality.

At Time 2, planned comparisons revealed that CAMs continued to perform with significantly greater accuracy than SRDs. Planned comparisons also revealed that the difference between RAMs and SRDs was significant for all conditions apart from auditory/orthographic. At Time 2, SRDs appear to have particular difficulty converting a visual code into a phonological one as is demonstrated by the large and significant discrepancy between SRDs and controls for the visual/phonological condition.

Further planned comparisons revealed that, whereas RAMs were significantly more accurate when the response instructions were consistent with the modality of presentation, SRDs and CAMs demonstrated this effect for visual stimuli only. For auditory stimuli, there was no significant difference between phonological and orthographic strategy accuracy for SRDs and CAMs. In fact, CAMs performed similarly for all conditions except for the visual/phonological condition which was performed with significantly less accuracy. As for the addition task, CAMs performed with high levels of accuracy, particularly at Time 2, suggesting that ceiling effects may confound their results.

Comparing Figures 14 and 15, it appears that SRDs made few gains for phonological strategy accuracy for either auditory or visual stimuli. Planned comparisons confirmed that although orthographic strategy use improved over time, SRDs did not significantly improve for phonological strategy use. This lack of improvement in accuracy for the phonological strategy was also observed for the addition task. As was also found for the addition task, group differences did not vary significantly with cohort for any of the interactions involving group.

Crossed responses

Following Martin et al. (2000), the purpose of the crossed response analysis was to determine whether RAMs over rely on a phonological strategy and whether SRDs demonstrate fewer orthographic intrusions on phonological tasks. Therefore, although separate 3[Group: SRD, CAM, RAM] x 3[Cohort: A, B, C] x 2(Time: 1, 2) x 2(Presentation: auditory, visual) x 2(Strategy: orthographic, phonological) ANOVAs were conducted for crossed responses for the addition and deletion tasks, only the higher order effects involving group and response strategy will be reported.

For the addition task, there was a significant Group x Presentation x Strategy interaction, $F(2, 89)=3.78$, $MSE=1.91$, $p<.05$, which is illustrated in Figure 16. Planned comparisons revealed that there were no significant differences between RAMs and SRDs for any of the conditions and both groups made significantly more crossed responses when the strategy required was inconsistent with stimulus modality. The latter effect was observed for CAMs but was significant only for visual stimuli indicating that they were less flexible in utilising a phonological strategy compared to an orthographic strategy in cross modal conditions. All groups made a similar number of crossed responses for the auditory/phonological condition. This effect did not vary significantly with any other variable. Therefore, for the addition task, there was little evidence to suggest that RAMs over rely on a phonological strategy and that SRDs experience fewer orthographic intrusions on phonological tasks given that there were no significant differences in crossed responses between these groups.

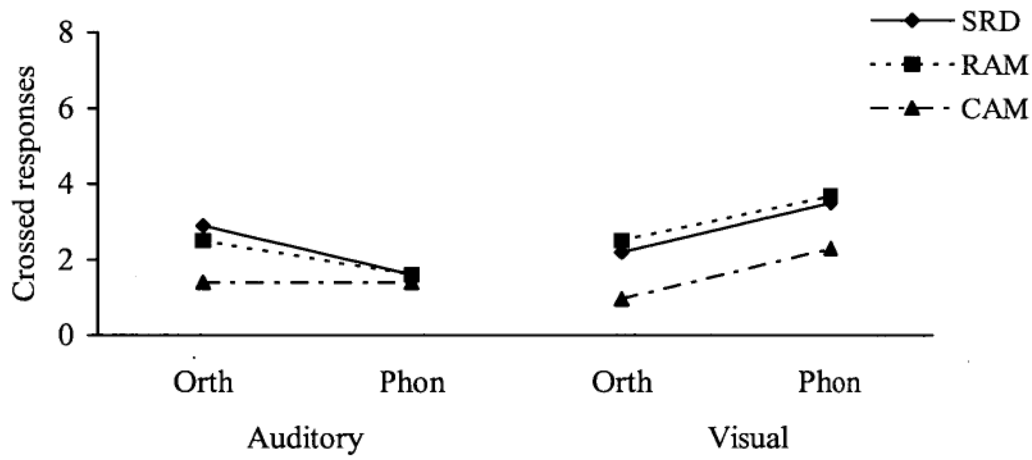

Figure 16. Group differences in the number of crossed responses on the addition task for orthographic and phonological strategy use depending on stimulus modality.

The Group x Presentation x Strategy interaction for the deletion task crossed responses was significant, $F(2,89)=8.21$, $MSE=1.62$, $p<.001$, and is illustrated in Figure 17. As can be seen in Figure 17, SRDs tended to make more crossed responses when a phonological strategy was required, particularly for visual stimuli whereas RAMs tended to make more crossed responses when an orthographic response was required, particularly for auditory stimuli. Although this suggests that SRDs tend to rely on an orthographic strategy (which is inconsistent with the hypothesis that SRDs will make fewer orthographic intrusions on phonological tasks) and that RAMs tend to rely on a phonological strategy, planned comparisons revealed that there were no significant differences between RAMs and SRDs across all conditions for crossed responses. CAMs made significantly fewer crossed responses than both SRDs and RAMs for all conditions except for the auditory/phonological condition for which there were no significant group differences. As for the addition task, RAMs and SRDs made more crossed responses for inconsistent tasks whereas this effect was observed only in the visual modality for CAMs.

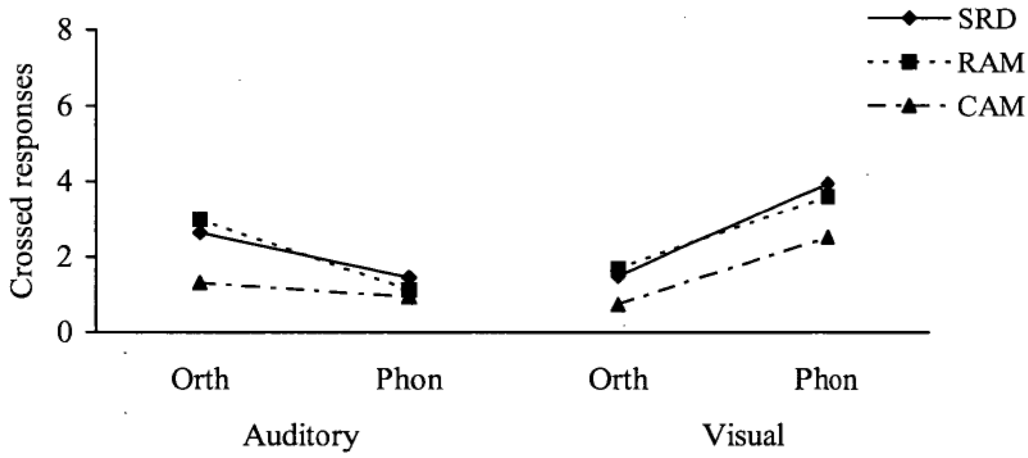

Figure 17. Group differences in the number of crossed responses on the deletion task for phonological and orthographic strategy use depending on stimulus modality.

For the deletion task, the Group x Presentation x Strategy interaction was found to vary significantly across time, $F(2,89)=3.22$, $MSE=1.20$, $p<.05$. At Time 1, although Figure 18 illustrates that RAMs make more crossed responses than SRDs for the auditory/orthographic condition, planned comparisons revealed that this difference was not significant.

As can be seen in Figure 19, at Time 2, SRDs made more crossed responses than RAMs ($p=.09$) and CAMs ($p<.05$) for the visual/phonological condition. In fact, SRDs did not make a significant improvement on this task whereas RAMs ($p<.05$) and CAMs ($p=.076$) tended to make fewer crossed responses for this condition over time. Therefore, SRDs continued to make a significant number of orthographic intrusions when a phonological strategy was required to manipulate visual stimuli.

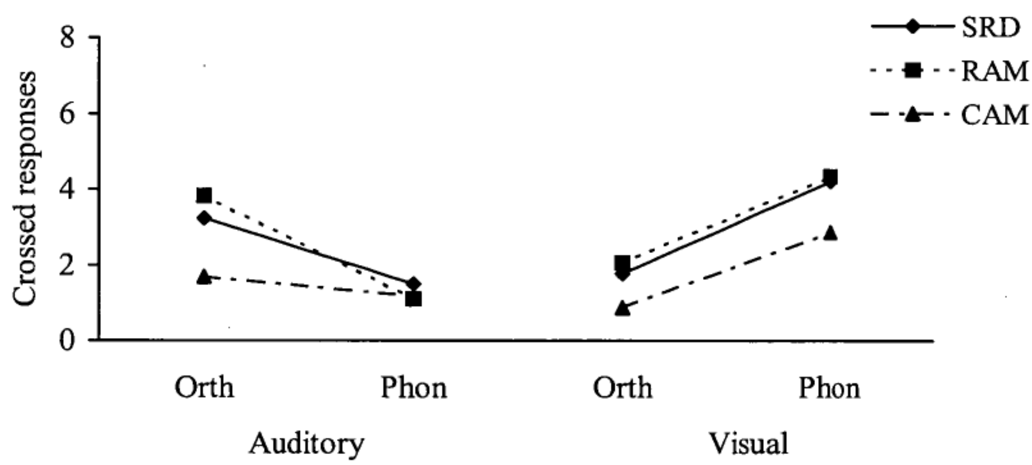

Figure 18. Group differences at Time 1 in crossed responses on the deletion task for phonological and orthographic strategy use depending on stimulus modality.

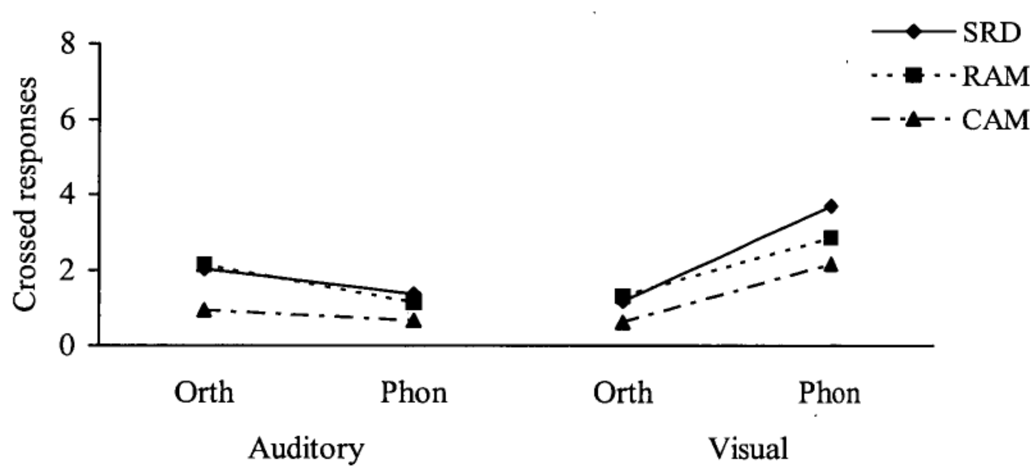

Figure 19. Group differences at Time 2 in crossed responses on the deletion task for phonological and orthographic strategy use depending on stimulus modality.

The Group x Presentation x Strategy interaction also varied significantly across cohort, $F(4,89)=3.54$, $MSE=1.62$, $p<.01$. To further clarify this interaction, separate Group x Time x Presentation x Strategy mixed ANOVAs were calculated for each cohort. Only effects involving group and response strategy are considered to be of interpretive significance for crossed responses. For Cohort A, there was a nonsignificant trend towards a Group x Presentation x Strategy interaction, $F(2,28)=2.81$, $MSE=1.15$, $p=.08$. Planned comparisons indicated that there were no significant differences between RAMs and SRDs for all conditions. CAMs made significantly fewer crossed responses than RAMs and SRDs for the orthographic strategy in both the visual and auditory modalities. There were no significant group differences for phonological strategy use, irrespective of modality.

The Group x Presentation x Strategy interaction was significant for Cohort B participants, $F(2,30)=9.32$, $MSE=1.83$, $p<.001$. Planned comparisons revealed that SRDs performed similarly to RAMs for all conditions except for when they were required to use an orthographic strategy in the auditory modality. In this condition, RAMs made significantly more crossed responses than both SRDs and CAMs, providing some support for the hypothesis that RAMs tend to over-rely on a phonological strategy. Planned comparisons revealed that SRDs performed similarly to CAMs for auditory stimuli whereas for the visual stimuli, SRDs tended to make more crossed responses for both the phonological ($p=.08$) and orthographic ($p=.09$) strategies compared to CAMs.

For Cohort C, there was an overall main effect for group, $F(2,31)=9.87$, $MSE=5.86$, $p<.001$, and post hoc tests (SNKs) revealed that CAMs ($M=0.96$) made significantly fewer crossed responses than RAMs ($M=2.07$) and SRDs ($M=2.51$). Group differences did not vary significantly across conditions, $F(1,31)=2.22$, $MSE=1.84$, $p=.13$. Although this interaction was not significant, planned comparisons were carried out to clarify previous findings that SRDs make fewer orthographic intrusions than controls on phonological tasks (Landerl at al., 1996). Cohort C SRDs made quantitatively more crossed responses for the phonological conditions compared to both RAMs and CAMs. Therefore, Cohort C SRDs appear to have less flexibility in utilising a phonological strategy in the visual modality and tend to make more orthographic intrusions than controls.

For the auditory modality, in which stimulus presentation is inconsistent with the requirement to use an orthographic strategy, both SRDs and RAMs made significantly more crossed responses that CAMs. For the visual condition, SRDs made fewer crossed responses than RAMs but more than CAMs, although these differences were not statistically significant. In contrast, RAMs made significantly more crossed responses than CAMs. This suggests that Cohort C RAMs are less flexible in adopting an orthographic strategy compared to older normal readers and tend to rely on the phonological strategy.

Results: Phonological and Orthographic Choice Tasks

Accuracy

A 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] x 2(Time: 1,2) x 2(Task: phonological, orthographic) mixed ANOVA was conducted for phonological and orthographic choice task accuracy to investigate group and cohort differences in orthographic and phonological processing abilities over time. The significant Group x Cohort interaction, $F(4,87)=3.03$, $MSE=22.03$, $p<.05$, is shown in Figure 20. CAMs were significantly more accurate than SRDs across all cohorts. Although RAMs were also more accurate than SRDs at each level of cohort, this difference was significant only for Cohort A (SNKs). Therefore, older SRDs were comparable to their reading age matched controls for choice task accuracy overall. The increment in accuracy with each level of cohort was found to be significant for RAMs only. For SRDs and CAMs, accuracy improved from Cohort A to B but the increment from Cohort B to C was not significant.

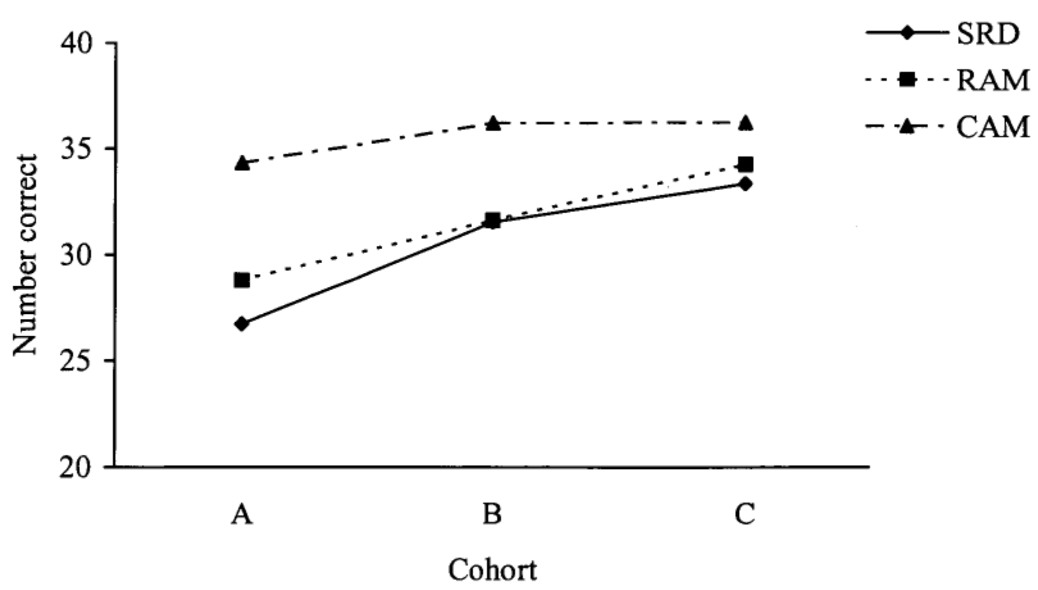

Figure 20. Group differences in overall choice task accuracy depending on level of cohort.

The Group x Task x Time interaction is shown in Figure 21 and indicates that although all groups were more accurate for the orthographic task compared to the phonological task, the degree of improvement over time for each task varied across Groups. For RAMs, there appears to be little difference in the degree of improvement for both tasks over time. Whereas SRDs show greater improvement for the orthographic task compared to the phonological task, the opposite is true for CAMs. Planned comparisons confirmed that SRDs showed significant improvement over time for the orthographic task but not the phonological task whereas CAMs made significant gains for the phonological but not the orthographic task. The observation that CAMs did not improve over time for the orthographic task has little interpretive significance given that this finding may be attributed to ceiling effects as can be seen in Figure 24. At Time 2, more than 70% of participants within each group scored 39 out of 40 or more on the orthographic choice task.

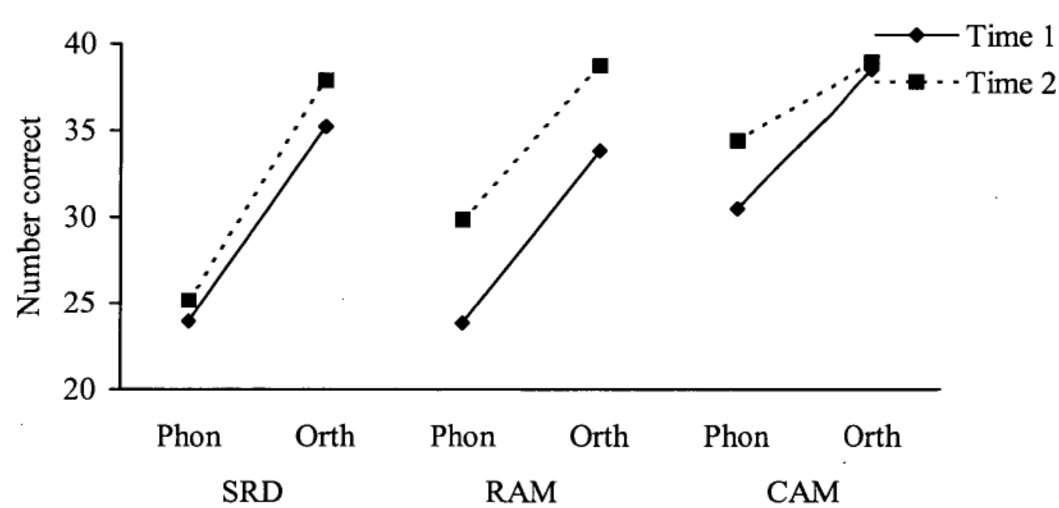

Figure 21. Changes over time for orthographic and phonological choice task accuracy for SRDs compared to controls.

This interaction also varied significantly with cohort, $F(4, 87)=3.61$, $MSE=11.26$, $p<.01$. In order to qualify this interaction, separate Group x Cohort x Time ANOVAs were conducted for each task. The results for the phonological task were relatively straightforward. Although the significant group main effect, $F(2,87)=35.96$, $MSE=27.84$, $p<.001$ revealed that overall, CAMs ($M=32.43$) were significantly more accurate than RAMs ($M=26.84$) who were in turn significantly more accurate than SRDs ($M=24.54$), group differences were further qualified by the significant interaction with time, $F(2,87)=4.80$, $MSE=19.30$, $p<.05$. As can be seen in Figure 22, RAMs appear to have an advantage over SRDs only at Time 2. Furthermore, although accuracy improved over time for all groups, SRDs show less improvement than the other groups. Planned comparisons revealed that RAMs were more accurate than SRDs at Time 2 only and that SRDs did not significantly improve over time for phonological choice accuracy.

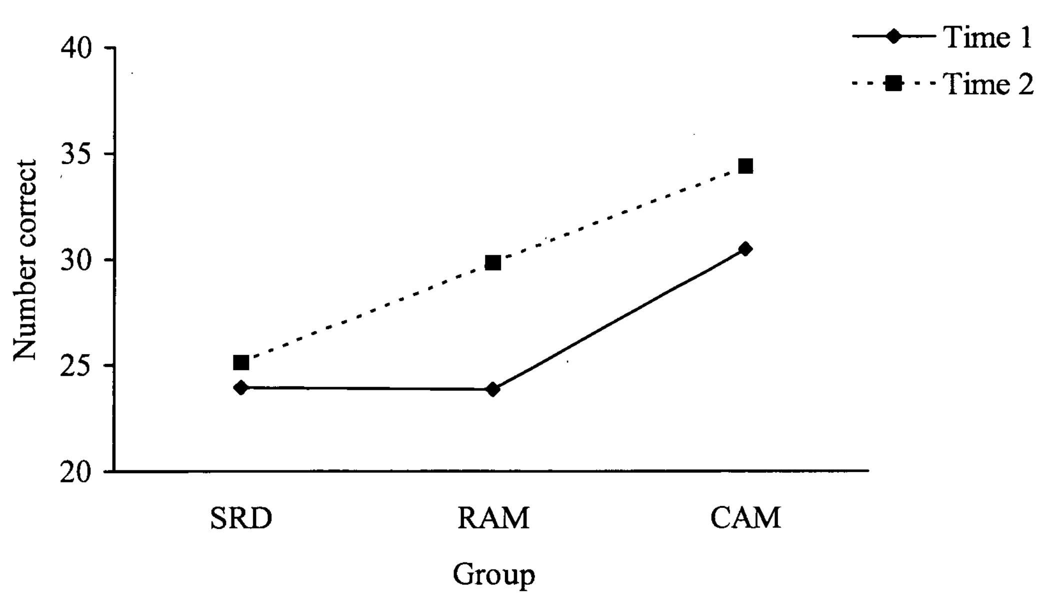

Figure 22. Changes over time for phonological choice task accuracy for SRDs compared to controls.

For the orthographic choice task, a significant issue impacting upon the interpretation of the results is that all the participants performed with high levels of accuracy. Therefore, ceiling effects make it difficult to interpret the results. However, there was a significant main effect for group, $F(2,88)=12.44$, $MSE=9.96$, $p<.001$, and SNKs revealed that CAMs ($M=38.79$) were significantly more accurate than RAMs ($M=36.27$) and SRDs ($M=36.54$) but the small advantage that SRDs had over RAMs was not significant. Although overall performance improved from Time 1 ($M=35.87$) to Time 2 ($M=38.53$), $F(1,88)=57.52$, $MSE=5.89$, $p<.001$, this effect varied with group, $F(2,88)=14.34$, $MSE=5.89$, $p<.001$. Planned comparisons revealed that only SRDs and RAMs improved significantly over time as shown in Figure 23.

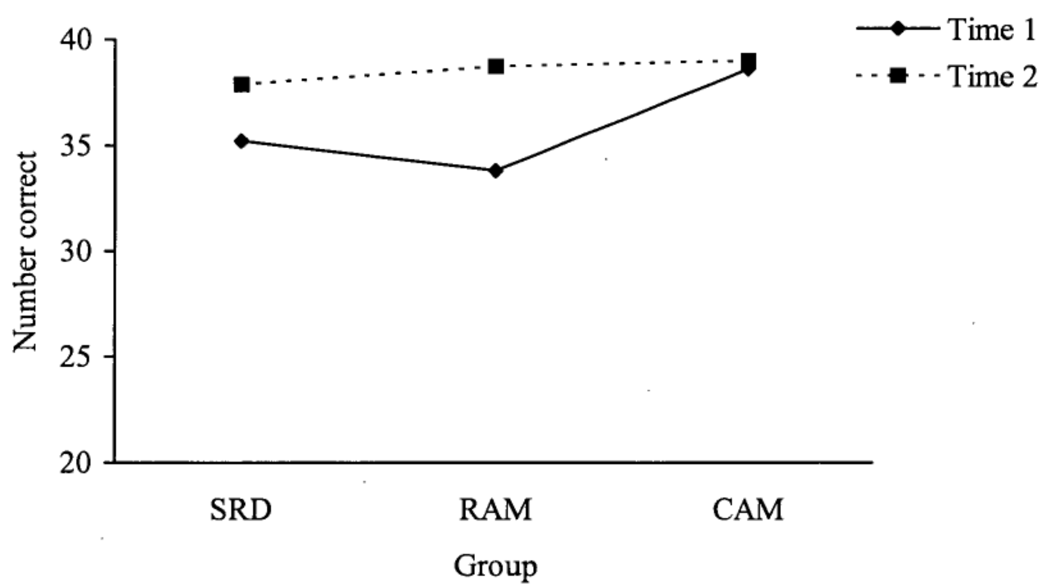

Figure 23. Changes over time for orthographic choice accuracy for SRDs compared to controls.

This interaction also varied across cohorts, $F(4,88)=3.23$, $MSE=5.89$, $p<.05$, and this effect is depicted in Figure 24. As can be seen, Cohort B and C SRDs tended to perform at a level commensurate with aged peers at Time 1 and Time 2. Planned comparisons confirmed that SRDs were significantly less accurate than CAMs in Cohort A only. Generally, SRDs tended to perform at a level commensurate with reading age peers, although Cohort B SRDs tended to be more accurate than RAMs at Time 1 (p=.08). Cohort A SRDs did not differ from RAMs at Time 1, however at Time 2 they were significantly less accurate than RAMs, even though both groups had improved significantly over time. However, the actual difference in performance is very small and this result has little interpretive validity due to ceiling effects.

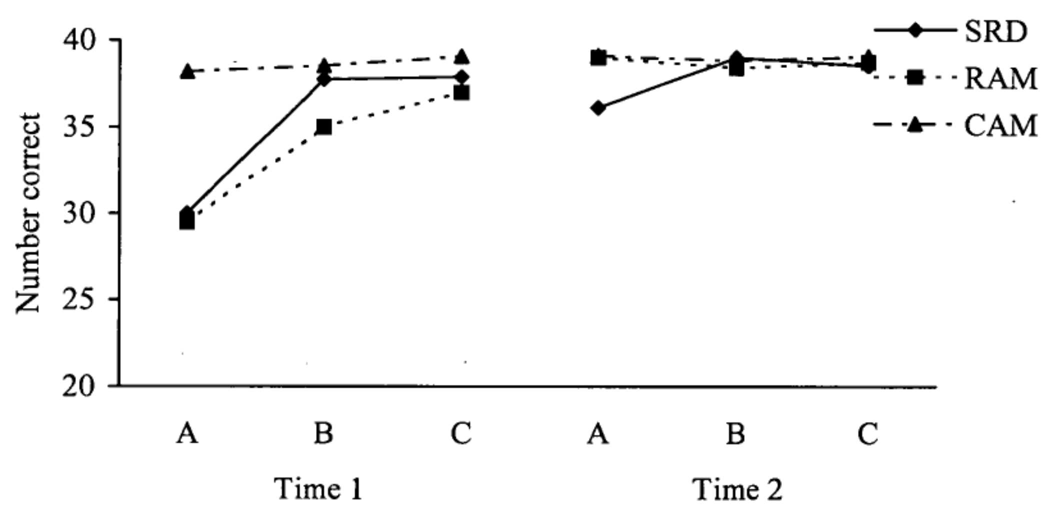

Figure 24. Changes over time for orthographic choice accuracy for SRDs compared to controls at each level of cohort.

Effect of Spelling Accuracy on Orthographic Choice Accuracy

It has been argued that the orthographic choice task is simply a spelling recognition task that relies on word-specific knowledge and is not a pure measure of orthographic coding ability (Berninger & Abbott, 1994; Lennox & Siegel, 1994). Therefore, a 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] x 2(Time: 1,2) x 2(Spelling accuracy: correct, incorrect) mixed ANOVA was conducted on the orthographic choice accuracy data to determine whether orthographic choice accuracy differed depending on whether the participants could accurately spell the words. Not all participants were included in this analysis given that many of them could correctly spell all the target items. The main effect for spelling accuracy was not significant, $F(1,66)=3.48$, $MSE=96.03$, $p=.067$, although participants tended to be more accurate for items that they could spell correctly ($M=93.81\%$) compared to incorrectly spelled items ($M=91.55\%$). There was a nonsignificant trend towards a Group x Spelling accuracy interaction, $F(2,66)=3.11$, $MSE=96.03$, $p=.05$ and this is shown in Figure 25. Planned comparisons revealed that spelling accuracy significantly facilitated the performance of RAMs. There were no significant differences between SRDs and RAMs for both spelling types. Although SRDs performed similarly to CAMs for correctly spelled items, CAMs tended to be more accurate than SRDs for incorrectly spelled items ($p=.053$). Therefore, although SRDs were not significantly facilitated by spelling accuracy, compared to CAMs they tended to be less accurate if they could not correctly spell the target word.

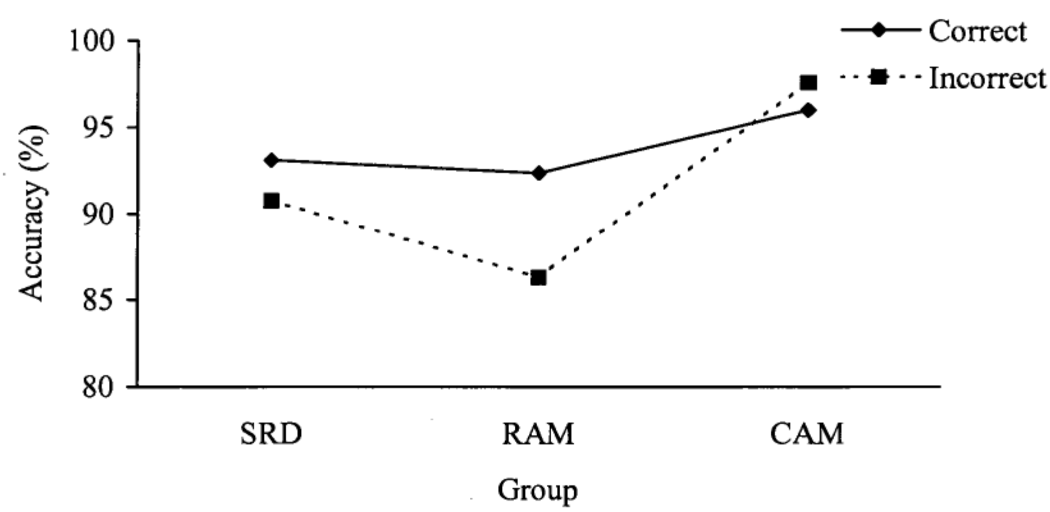

Figure 25. Group differences in orthographic choice accuracy for correctly and incorrectly spelled targets.

Reaction Time

A 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] x 2(Time: 1,2) x 2(Task: phonological, orthographic) mixed ANOVA was conducted for phonological and orthographic choice task reaction time to investigate group differences in orthographic and phonological processing speed over time. Overall, the orthographic task (M=1656.27) resulted in faster reaction times than the phonological task (M=1787.19), $F(1,87)=376.83$, MSE=135464.00, $p < .001$. There was an overall significant main effect for group, $F(2,87)=3.64$, MSE=405550.60, $p<.05$, with CAMs (M=1624.76) having the fastest reaction time followed by SRDs (M=1705.72) and RAMs (M=1834.72). SNKs revealed that only the difference between CAMs and RAMs was significant. There were no other significant effects involving group differences.

Orthographic Awareness

At Time 2 a second orthographic task was administered to investigate the participant's knowledge of orthographic rules. This task was included as it is not confounded by spelling ability because the targets and foils are nonwords and should offer a more accurate measure of orthographic knowledge compared to the orthographic choice task. Separate 3[Group: SRD, RAM, CAM] x 3[Cohort: A, B, C] ANOVAs were conducted for orthographic awareness accuracy and reaction time.

Accuracy

The main effect for group was not significant, $F(2,88)=2.27$, MSE=4.92, p=.11, indicating that although SRDs (M=10.69) were less accurate than RAMs (M=11.16) and CAMs (*M*=11.88), these differences were not significant. Group differences did not vary significantly across cohort, $F(4,88)=.58$, $MSE=4.92$, $p=.68$.

Reaction Time

Overall, there were no significant differences in reaction times for orthographic awareness across groups, $F(2,88)=.37$, $MSE=264354.80$, $p=.70$, although the means indicate that SRDs (*M*=1908.63) were faster than RAMs (*M*=2006.18) and CAMs (*M*=2004.66). Although there was a significant Group x Cohort interaction, $F(4,88)=2.88$, $MSE=264354.80$, $p=.03$, SNKs revealed that none of the mean differences were significant.

General Discussion and Conclusions

There were two main research questions that this thesis aimed to address. The first was whether SRDs, given that they were expected to demonstrate a phonological deficit, would make few developmental gains for phonological processing measures but improve significantly over time on measures of orthographic processing. A second question was that if SRDs do demonstrate significant improvement over time for orthographic processing measures, do they improve to the same extent as normally achieving readers given that they are expected to have a phonological processing deficit. That is, this thesis aimed to determine whether SRDs can become skilled at orthographic processing and use these skills to compensate for a phonological processing deficit.

This study utilised grapheme-phoneme addition and deletion tasks as measures of phonological processing that are thought to be highly related to reading ability as they involve segmentation, manipulation, and blending operations (Bowey, 1996; Muter 1994; Muter et al., 1998; Yopp, 1988). The addition and deletion tasks were also designed to measure accuracy and flexibility in utilising orthographic and phonological strategies to arrive at the required response. Overall, participants were more accurate for the addition task compared to the deletion task suggesting that blending or synthesis is an easier operation than deletion or segmental analysis. This is consistent with Yopp (1988) who also found that phoneme blending was easier than phoneme deletion in a review of tests of phonological awareness. One hypothesis that accounts for this is that synthesis tasks only require phonological sensitivity, which is considered to be a more fundamental knowledge about phonology, whereas analysis tasks place greater reliance on phonological awareness and involve a more complete awareness of individual phonemes (Perfetti et al., 1987).

There was no evidence that SRDs have more difficulty with phoneme addition compared to phoneme deletion. This is inconsistent with Berndt et al.'s (1996) findings that patients with acquired dyslexia had more difficulty with blending a sound with an already existing word body (addition) than manipulating and segmenting words and their constituents (deletion). One explanation for this is that the deficits underlying acquired dyslexia cannot be generalized to developmental dyslexia. However, like the current study, Wesseling and Reitsma (2000) found that reading disabled children did not demonstrate a significant deficit for phoneme blending and also reported evidence that the ability to blend phonemes becomes less important for the development of skilled reading beyond early reading acquisition.

Task differences were differentially affected by strategy use across groups. As a group, SRDs demonstrated decreased accuracy for the deletion task compared to the addition task but only when a phonological strategy was required. This suggests that SRDs had a particular difficulty with phoneme deletion but could manipulate graphemes with comparable accuracy for both the addition and deletion operations. The difficulty that SRDs had with phoneme deletion may be because they had to isolate the phoneme to be deleted. For the phoneme addition task, the phoneme was pronounced and clearly identified for them whereas, for the phoneme deletion task, although the phoneme to be deleted was pronounced, they had to segment the word in order to isolate that phoneme before they could carry out the deletion operation. This confirms previous findings that SRDs have a particular difficulty with phoneme deletion (Manis et al., 1993; Martin et al., 2000) and provides support for the small unit hypothesis that suggests SRDs have an underlying difficulty manipulating phonology at the phonemic or small unit level (Duncan & Johnston, 1999; Gottardo et al., 1999). The observation that SRDs had a particular difficulty with phoneme analysis but had phoneme synthesis skills appropriate for their reading age also lends some support to Perfetti et al.'s (1997) hypothesised distinction between phonological sensitivity and phonological awareness.

In contrast, normally achieving readers were more accurate at addition compared to deletion when they were required to use an orthographic strategy. The combination of the orthographic strategy and the addition operation appeared to have additive effects on the performance of normal readers. Perhaps normal readers did not show task differences for the phonological strategy because overall, participants were less accurate at using this strategy and therefore the advantage for the addition task was lost.

The reading age match control group was the only group that demonstrated task differences depending on stimulus modality. They did not show any significant task differences for the visual stimuli but were more accurate at addition compared to deletion for auditory stimuli. It may have been more difficult for this group to perform the deletion operation in the auditory modality as it may have placed more demands on working memory because it involved a greater degree of manipulation than addition as they had to isolate the phoneme to be deleted. Younger normal readers appeared to be more susceptible to this than older normal or poorer readers.

For both the addition and deletion tasks, participants were more accurate when the response strategy required was consistent with the modality of presentation. That is, orthographic strategy use was facilitated when the stimuli were presented in the visual modality whereas phonological strategy use was facilitated by auditory stimulus presentation. This is consistent with previous research that has used the forced-choice grapheme-phoneme deletion task with SRDs (Martin et al., 2000) and normally achieving readers (Binns, 1997; Claydon, 1996). An interesting finding with respect to inconsistent tasks was that for both the addition and deletion tasks, the auditory/orthographic condition resulted in greater accuracy than the visual/phonological condition suggesting that it was easier for participants to manipulate an auditory code into a visual one compared to converting a visual letter string into a phonological code. This is interesting given that translating a visual code into a phonological one is the task that most closely simulates reading, yet overall, the participants had the greatest difficulty with this process.

With respect to the effects of reading ability on the development of grapheme-phoneme addition skills, chronological age match controls were consistently more accurate than both reading age match controls and SRDs over time. Although the overall performance of SRDs was commensurate with reading aged peers at Time 1, they tended to be less accurate than RAMs at Time 2, particularly for orthographic strategy use. Although SRDs did improve over time for grapheme addition, it was not to the same extent as their reading age peers. This may be because the reading age match controls tended to develop an advantage for orthographic strategy use over time, whereas SRDs did not demonstrate a significant advantage for either strategy at Time 1 or Time 2. Phoneme addition accuracy did not improve significantly over time for SRDs but was consistent with reading age peers at both Time 1 and Time 2. Although the discrepancy between SRDs and reading age match controls for grapheme addition suggests SRDs have a specific difficulty in utilising an orthographic strategy, when group differences were analysed across each condition irrespective of time, there were no significant differences between SRDs and their reading age peers for any of the four conditions.

SRDs did not differ from reading age match controls with respect to flexible strategy use, as both groups were facilitated by consistency between response strategy and stimulus modality. Therefore, SRDs did not appear to have any difficulty with respect to flexible strategy use as they did not have any greater difficulty with inconsistent conditions compared to reading age peers for the addition task. In contrast, chronological age match controls illustrated greater flexibility in applying the appropriate strategy for auditory stimuli whereas visual stimuli continued to facilitate orthographic strategy use for that group.

Although SRDs were expected to be significantly less accurate than normally achieving readers at using the phonological strategy in the auditory modality providing support for the phonological deficit hypothesis, the difference between SRDs and chronological age match controls approached significance and there was no significant difference between SRDs and reading age match controls. Therefore, there is little evidence to support the hypothesis that SRDs would show a deficit in utilising a phonological strategy compared to controls for the addition task and this finding is again consistent with previous findings that SRDs do not show a deficit for phoneme synthesis skills (Wesseling & Reitsma, 2000). As these group effects did not vary across cohort, there did not appear to be any significant age related differences in the development of accuracy and flexibility of orthographic and phonological strategy use for SRDs. The main finding with respect to the effect of reading ability on grapheme-phoneme addition accuracy was that the development of phoneme synthesis skills appeared to be impaired for SRDs compared to normal controls for both phonological and orthographic strategy use but they did not appear to have a specific deficit on this task.

As was found for the addition task, SRDs performed similarly to reading age peers at Time 1 for the deletion task. They were however less accurate at Time 2 for the deletion task. Their overall accuracy was consistently poorer than chronological age match controls across time. In contrast to the addition task, the advantage that reading age match controls had over SRDs on the deletion task appears to be more evident for the phonological strategy, regardless of modality, whereas SRDs were comparable to reading age peers when the task required an orthographic strategy. This provides evidence for a specific phonological deficit as indexed by phoneme deletion accuracy. The demonstrated difficulty that SRDs had in utilising the phonological strategy is consistent with Martin et al. (2000) but deviates from previous studies that have indicated that SRDs do not differ from reading age peers in their use of phonological codes for auditory stimuli (Snowling, 1980; Thompson & Johnson, 2000).

Martin et al. (2000) also found that SRDs were superior to reading age match controls and performed similarly to chronological age match controls for the orthographic strategy. However, this was not the case for the current study as SRDs were consistently poorer than chronological age peers for all conditions across time. Further evidence indicated that at Time 2, SRDs were significantly less accurate than reading age match controls for all conditions apart from when they were required to use the orthographic strategy for stimuli presented in the auditory modality. Therefore in addition to a phonological deficit, they were not as accurate as reading aged controls at utilising the orthographic strategy for visual stimuli but were comparable for flexible application of the orthographic strategy when the response instructions were incompatible with the stimulus modality.

The finding that SRDs were significantly less accurate than reading age peers for orthographic strategy use in the visual modality is inconsistent with predictions based on the hypothesis that SRDs have intact orthographic processing skills, particularly since the visual modality is expected to facilitate a response based on orthographic instructions. One possibility is that SRDs were less accurate than reading age peers at using the orthographic strategy in the visual modality because they are poorer at spelling. To confirm this, it would have been useful to get them to spell the stimulus words and derivatives, although it is likely that a spelling deficit would also affect their accuracy for orthographic strategy use in the auditory modality.

Reading age match controls may have found it more difficult to perform the grapheme deletion task in the auditory modality because there were fewer cues for them to derive the correct spelling if they could not see the stimulus word. Alternatively, reading age match controls may have made more phonological intrusions on the orthographic task because auditory stimuli usually facilitate a phonological response. SRDs are less likely to demonstrate this effect because they are thought to have a weak link between phonological and orthographic representations (Landerl et al., 1996). This hypothesis was supported by the observation that reading age matched controls made more crossed responses on the auditory/orthographic task compared to SRDs, indicating that they were more reliant on the phonological strategy to perform this condition.

It has been noted earlier in the discussion that all groups found that the most difficult task was phoneme deletion for visual stimuli. However, at Time 2, SRDs had the most difficulty converting a visual code into a phonological one, indicating that they were less flexible in utilising a phonological strategy when the modality was inconsistent with response instructions compared to normal controls. Therefore, this provides partial support for the prediction that SRDs would have more difficulty with cross modal conditions than controls based on previous findings (Snowling, 1980; Fox, 1994; Landerl et al., 1996). Although SRDs had more difficulty accessing phonological information from a written code, they performed similarly to reading age peers when they were required to access orthographic information from a spoken code. Based on Snowling's (1980) conclusions, this finding also suggests that SRDs are poorer at decoding using GPC rules and again points to a specific phonological deficit.

Reading age match controls demonstrated an effect of consistency for both auditory and visual stimuli whereas SRDs and their chronological age peers demonstrated this effect only for visual stimuli. That is, for auditory stimuli, SRDs demonstrated similar levels of accuracy for both the phonological and orthographic strategies. This is likely to be because they found phoneme deletion to be particularly difficult for visual stimuli whereas they performed similarly to reading age peers for orthographic strategy in the auditory modality. Chronological age match controls also demonstrated greater flexibility in utilising the appropriate strategy for auditory stimuli.

Although orthographic strategy use improved over time for SRDs, they did not demonstrate a significant improvement for phonological strategy use. Over the course of the longitudinal study, SRDs demonstrated greater accuracy and flexibility in utilising an orthographic strategy and demonstrated a phonological deficit at Time 2. In addition, SRDs had greater difficulty with grapheme deletion in the visual modality compared to reading age controls. The only measure on which they performed at a level comparable to reading age peers at Time 2 was when they were required to complete a grapheme deletion task in the auditory modality, but this may be because reading age match controls tended to be less accurate for this condition because they made more crossed responses than SRDs. The pattern of results observed for SRDs was not significantly affected by their chronological age.

Following Martin et al. (2000), the purpose of the crossed response analysis was to determine whether younger normal readers, or reading age match controls, overly rely on a phonological strategy and whether SRDs demonstrate fewer orthographic intrusions on phonological tasks. The crossed response data may also provide evidence as to whether orthographic information may have interfered with performance on the phoneme deletion task as has been previously found for beginning and skilled readers (Seidenberg & Tanenhaus, 1979; Ehri & Wilce, 1980; Donnenwerth-Nolan, Tanenhaus, & Seidenberg, 1981; Tunmer & Nesdale, 1982;

Barron, 1994). It may also help clarify whether this finding extends to SRDs as there have been some inconsistencies in the literature as to whether they rely on orthographic information to the same extent as normal readers (Perin, 1983; Rack, 1985; Zecker, 1991; Bruck, 1992).

For the addition task, there were no significant differences between SRDs and their reading age peers for any of the conditions and both groups made more crossed responses when the strategy required was inconsistent with stimulus modality. The latter effect was observed for CAMs but only for visual stimuli indicating that they were less flexible in utilising a phonological strategy compared to an orthographic strategy in cross modal conditions and is consistent with the findings for overall accuracy. Therefore, there was little evidence to suggest that younger normal readers overly rely on a phonological strategy and that SRDs experience fewer orthographic intrusions on phonological tasks given that there were no significant differences in crossed responses between these groups. All participants elicited crossed responses to some extent indicating that orthographic and phonological processes are not activated in isolation. However, older skilled readers (chronological age match controls) were less likely to elicit crossed responses than younger (reading age match controls) and poorer (SRDs) readers.

The main finding for the deletion task was that SRDs made more crossed responses than normally achieving readers when they were required to use the phonological strategy in the visual modality and the number of crossed responses made by SRDs for this condition did not change significantly over time. Therefore, SRDs continued to make a significant number of orthographic intrusions when a phonological strategy was required to manipulate visual stimuli. This suggests that SRDs are less accurate than controls on this task because they are more likely to use an orthographic strategy. This effect was also found for Cohort C SRDs irrespective of time suggesting that it tends to become prominent later in development for SRDs. This is consistent with previous findings that dyslexic readers rely more on orthographic information than normal readers and use it to compensate for poor phonological processing (Bruck, 1992; Foorman & Liberman, 1989; Rack, 1985) and does not support Landerl et al. (1996) who found that dyslexic readers have a lower number of orthographic intrusions compared to controls. Although this finding may depend upon the age at which SRDs are tested, it potentially impacts on the hypothesis that the central problem in dyslexia may be a weak link or independence between phonological and orthographic representations (Perin, 1983; Zecker, 1991; Bruck, 1992; Landerl et al., 1996).

The finding that SRDs have poorer decoding skills than reading age peers, as indexed by the WRMT-R Word Attack subtest, provides further evidence for a phonological deficit that appeared to be stable over time given that this group difference was observed at Time 1 and Time 2. An additional measure of decoding skills, the Martin and Pratt Nonword Test, provided more evidence for a specific phonological processing deficit for SRDs given that they were significantly less accurate than both control groups for nonword reading. This was consistent across cohorts. These findings are consistent with meta-analytic studies that have shown SRDs perform poorly on measures of nonword reading compared to normally achieving readers (Rack et al., 1992; van Ijzendoorn & Bus, 1994).

Converging evidence for a phonological deficit was provided by the phonological choice task, which is hypothesised to rely on intact decoding skills for accurate performance (Olson et al., 1985). SRDs were consistently less accurate than chronological age peers over time. Although SRDs performed similarly to reading age peers at Time 1, they did not demonstrate any significant improvement over time and were significantly less accurate than reading age peers at Time 2. Reaction time data did not discriminate between SRDs and control groups.

With respect to the development of word identification for SRDs compared to normally achieving readers, SRDs had higher word identification scores than reading age peers at Time 1 whereas by Time 2, reading age match controls had significantly surpassed the SRDs on this measure. Therefore, although a causal relationship cannot be identified in the context of this study, one conclusion that could be drawn is that the poor decoding skills of SRDs impacted upon the development of automatic word recognition skills. This is consistent with Share's (1995, 1999) self teaching mechanism and the evidence provided by Stuart and Coltheart (1988) that the development of decoding skills leads to an increase in sight word vocabulary. Furthermore, Aaron et al. (1999) also found that poor decoding skills were strongly related to poor sight word reading and that sight-word reading appears to be based on decoding skills. These findings are also consistent with Manis et al.'s (1993) longitudinal results that indicated that the delay in word identification skills was mainly attributed to arrested development on tasks requiring phoneme analysis skills such as phoneme deletion and nonword reading.

Although hypotheses based on the dual route model of word recognition predict that SRDs will demonstrate a reduced regularity effect because they can only rely on the orthographic route to recognise words, the current results did not provide any significant support for this prediction. The current results demonstrated that SRDs were more accurate at reading regular words compared to irregular words and their overall performance on both tasks was consistent with their reading age. This is consistent with previous findings that a nonword reading deficit does not necessarily result in the regularity effect being attenuated or absent (Brown, 1997; Metsala, Stanovich, & Brown, 1998). However, like Castles and Coltheart (1993), the results also suggest that SRDs may have a secondary difficulty in using the orthographic route because their ability to read irregular words was delayed compared to chronological age peers. This provides further support to the premise of this thesis that a phonological deficit impacts upon the development of orthographic processing abilities. Although SRDs improved significantly over time, they did not improve to the same extent as reading age peers, particularly for Cohorts A and C as reading age match controls in these cohorts were more accurate than SRDs at Time 2. The lack of discrepancy between Cohort B SRDs and their reading age peers at Time 2 may be due to the reported difference in delay between testing sessions, although Cohort B SRDs had higher raw scores than Cohort B reading age match controls at Time 1.

Measures of comprehension were included in the study to determine the impact that a reading disability might have on both reading and listening comprehension. For reading comprehension as measured by the WRMT-R Passage Comprehension subtest, SRDs were consistently poorer than chronological age peers in each cohort but they performed at a level consistent with (Cohorts A and C) or superior to

(Cohort B) what would be expected given their reading age. However, the advantage that SRDs had over reading age peers was more robust at Time 1. Similarly, the listening comprehension skills of SRDs were superior than what would be predicted given their reading age but their performance deviated from that of chronological age peers over the longitudinal course of the study. Therefore, although there was evidence for a phonological processing deficit, this does not appear to have had a significant impact upon comprehension abilities as SRDs were simply delayed on these measures and performed at a level at least consistent with their reading age.

The orthographic choice task was designed to isolate orthographic coding abilities, as participants could not derive an accurate response based on the phonological properties of the words (Olson et al., 1985). There was no overall difference for accuracy and reaction time measures between SRDs and reading age peers for the orthographic choice task, which is consistent with the majority of studies that have previously utilised this task (Manis et al., 1988, 1993, 2000; Olson et al, 1985, 1989). The only exception to this was that Cohort A SRDs were less accurate than their reading age peers at Time 2, which suggests that younger SRDs did not make as much improvement over time as their reading age peers. The current results were not consistent with previous findings that SRDs have faster reaction times compared to reading age match controls (Olson et al., 1985, 1989) as there was no significant discrepancy between SRDs and reading age match controls for reaction time. Older SRDs performed similarly to chronological age peers for orthographic choice accuracy and there were no group differences for reaction time. In summary, the orthographic processing skills of SRDs appear to be relatively intact, although the data need to be interpreted with caution due to the high levels of accuracy for all participants, particularly at Time 2.

It has been suggested that SRDs do not make normal progress on reading tasks because they are unable to compensate for their phonological deficit. Some authors have suggested that this is because they have less accurate or less precise orthographic representations (Lundberg & Hoien, 1990; Manis et al., 1990). For example, Manis et al. (1990) found that SRDs were less accurate on orthographic tasks that require knowledge of orthographic patterns for specific words. In the current study, the orthographic choice task was a measure of access to orthographic representations in the lexicon. However, only the youngest SRDs (in Cohort A) appear to have developed less accurate orthographic representations, as they were the only group of SRDs to perform with less accuracy over time compared to reading age peers. However, because of the ceiling effects observed on this task, it is difficult to draw accurate conclusions about the development of orthographic representations in older SRDs based on the orthographic choice task data.

When the accuracy data was corrected for spelling accuracy, there were no group differences for correctly spelled targets. Therefore, SRDs performed as well as controls for orthographic choice task accuracy if they could spell the words. However, as a group they were not more accurate for correct compared to incorrect spellings. This suggests that the performance of SRDs on this task is not impaired if they have inaccurate orthographic representations of target words. Only reading age match controls were more accurate if they could spell the targets compared to targets they could not spell. Chronological age match controls were more accurate than both

SRDs and reading age match controls for targets that they had incorrectly spelled suggesting that chronological age match controls benefited more than the other two groups from targets and foils being presented simultaneously. The results for orthographic choice are not consistent with Berninger's (1994) proposal that SRDs are likely to perform better if targets and foils are presented simultaneously. This is because SRDs were not facilitated by simultaneous presentation for targets that they could not spell.

The orthographic awareness task was included as it was considered to be a more sensitive measure of orthographic knowledge than the orthographic choice task (Siegel et al., 1995). However, the accuracy and reaction time measures for orthographic awareness were consistent in that all participants tended to perform similarly and this result is inconsistent with previous studies that have found that SRDs outperform reading age peers on this task (Siegel et al., 1995; Stanovich & Siegel, 1994). This suggests that all participants possessed a similar degree of knowledge of the orthographic rules required to complete this task. Therefore, SRDs were comparable to reading age and chronological age peers for orthographic tasks requiring word specific information and knowledge of English orthography.

The computer-administered measures of orthographic processing may not have been sensitive to group differences as all groups tended to elicit high levels of accuracy. An alternative task would be to use naming speed as a measure of orthographic processing as processes indexed by naming speed are involved in the development of orthographic codes and ease of access to them. Naming speed has been found to discriminate between poorer readers and controls and reliably predicts reading achievement (Bowers, Golden, Kennedy, & Young, 1994; Catts, Fey, Zhang, & Tomblin, 1999; Manis et al., 2000). Wolf, Pfeil, Lotz, and Biddle (1994) propose that phonological factors are important but they cannot account for the heterogeneity of reading impairment or the incidence of naming speed deficits. Naming speed deficits may be a marker for the disruption of automatic processes underlying the induction of orthographic processes and rapid access to lexical codes.

Although many theorists utilise computer modelling to simulate orthographic and phonological representations (Colheart et al., 1993, 2001; Plaut et al., 1996; Siedenberg & McClelland, 1989; Zorzi et al., 1998), another body of work utilises online recording of the brain's electrophysiological responses to task demands in order to isolate indices that reflect phonological and orthographic processes and attempt to discriminate between dyslexic and normal readers (Kujala, Karma, Ceponiene, Belitz, Turkkila, Tervaniemi, & Naatanen, 2001; Lovrich et al.1996; 1997; McPherson, Ackerman, Holcomb, and Dykman, 1998). An extension of the current research could be to record event-related potentials of SRDs and normally achieving readers while they perform the grapheme-phoneme tasks and the phonological and orthographic choice tasks in order to obtain an online measure of the processing resources they utilise in order to meet task demands.

One issue that may differentiate this study from previous research is that reading age matches were dependent on the WRMT-R Basic Skills cluster, which incorporates both word attack and word identification skills. In contrast, Rack et al.'s (1992) meta-analytic study indicated that a large body of previous research has only used a single measure of word recognition to match SRDs with reading age controls.

Furthermore, van Ijzendoorn and Bus (1994) indicated that reading tests that focus on isolated irregular word reading are a more adequate measure of word recognition skills for matching purposes. A more considered approach to matching groups for reading age is recommended for future research that adopts a reading-level design.

The fact that SRDs and reading age match controls were initially matched to some extent for both decoding and isolated word recognition skills may account for the observation that these groups tended to perform similarly at Time 1, particularly for phonological processing measures. This has implications for making an accurate assessment as to whether SRDs show normal but delayed rather than deviant performance. However, this finding appears to be consistent with Snowling et al. (1998) who found that at Time 1 SRDs were comparable to reading age peers, indicating normal but delayed development. However, at Time 2, dyslexics were poorer than reading age peers providing evidence for an atypical pattern of development.

Summary and conclusions

The grapheme-phoneme deletion tasks indicated that a significant problem for SRDs appears to be the isolation of phonemes in phonological analysis tasks, particularly for visual stimuli, as they tend to rely on an orthographic strategy. This is more prominent for older SRDs because the findings indicate that orthographic strategy use improved over time but phonological strategy use did not. Therefore, there is some evidence that SRDs may attempt to compensate for poor phonological processing by relying on their superior orthographic processing skills, at least for phoneme deletion tasks presented in the visual modality, although in this case it does not facilitate performance. The finding that SRDs have a particular difficulty in being able to segment the pronunciation of words to detect phonemes also provides evidence that SRDs have difficulty in making a transition from Ehri's (1992, 1997) partial alphabetic to full alphabetic phases and that they have a specific deficit in graphophonemic knowledge as described by Ehri and Soffer (1999).

The results are also consistent with Share's (1995, 1999) self teaching hypothesis as SRDs were identified as having a phonological deficit based on their performance on nonword reading, phonological choice, and phoneme deletion tasks and, overall, were unable to achieve word recognition skills consistent with their chronological or reading age. Therefore, it is argued that SRDs do not become skilled readers because they have poor phonological processing skills. A further prediction was that if SRDs were found to have a phonological deficit, they were likely to make few developmental gains for phonological processing measures. This prediction was supported as SRDs did not demonstrate significant improvement over a two-year period for phonological coding skills or for phonological strategy use for both the addition and deletion tasks. Although their nonword reading skills did improve, these more complex tasks showed an atypical developmental course compared to normally achieving peers.

Overall, the performance of SRDs on the orthographic tasks was consistent with what would be expected given their reading age, providing little evidence for an orthographic processing deficit. Although SRDs did show significant improvement over time for orthographic processing measures, they tended to show an atypical developmental pattern compared to controls, particularly for the addition and deletion tasks. Their knowledge of orthographic conventions in the English language was consistent with their chronological age, although this task did not discriminate between any of the groups. Few conclusions can be drawn from the orthographic choice task due to ceiling effects, particularly for older SRDs, although younger SRDs appear to have an atypical developmental pattern and develop less accurate orthographic representations compared to reading age peers.

In conclusion, the results provided further support for the well established finding that the central problem for SRDs is a phonological processing deficit. It appears that a failure to make significant developmental gains in phonological processing skills contributed to the discrepancy between SRDs and normally achieving readers on a standardised measure of word recognition. Although the conclusions about orthographic processing skills are more speculative, it appears that SRDs were unable to become skilled at orthographic strategy use compared to chronological age peers and although their orthographic processing skills did improve over time, they tended to demonstrate an atypical pattern of development compared to normally achieving readers. Although the orthographic processing skills of SRDs may have been superior to their phonological processing skills, they were unable to rely on these skills to compensate for a phonological deficit as their word recognition skills became significantly poorer than reading age peers over time. These findings support Share's (1995, 1999) self-teaching mechanism and the idea that the acquisition of orthographic representations is largely dependent on the successful operation of the phonological component of the model.

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Appendix A: ANOVA Tables for Screening Data Analyses

Table A1

Analysis of Variance for Nonverbal Ability Screening Data

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group	2	1421.30	126	341.27	4.16	0.02*
Cohort	2	615.74	126	341.27	1.80	0.17
Group x Cohort	4	435.19	126	341.27	1.28	0.28

$^*p<.05$.

Table A2

Analysis of Variance for Reading Age Screening Data

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group	2	265.44.42	126	45.24	586.77	<.0001*
Cohort	2	11268.42	126	45.24	249.09	<.0001*
Group x Cohort	4	7.18.51	126	45.24	15.88	<.0001*

$^*p<.05$.

Table A3

Analysis of Variance for Chronological Age Screening Data

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group	2	24714.32	126	17.54	1408.88	<.0001*
Cohort	2	13652.94	126	17.54	778.31	<.0001*
Group x Cohort	4	541.33	126	17.54	30.86	<.0001*

$^*p<.05$.

Table A4

Analysis of Variance for Discrepancy Between Reading Age and Chronological Age in Months (Lag)

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group	2	25925.56	126	43.09	601.60	<.0001*
Cohort	2	115.61	126	43.09	2.68	0.07
Group x Cohort	4	643.89	126	43.09	14.94	<.0001*

$^*p<.05$.

Appendix B: Grapheme-Phoneme Addition Task Stimuli

Table B1

Grapheme/Phoneme Addition Task: Condition 1 Response Sheet

Condition 1: Auditory Presentation - Orthographic Response Required

bead
are
own
me
go
lose
crow
ear

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
hut	***r***	***heart***	***hurt***	
heap	***c***	***keep***	***cheap***	
Test Items				
bead	*r*	*breed*	*bread*	
are	*c*	*car*	*care*	
own	*t*	*tone*	*town*	
me	*t*	*meet*	*met*	
go	*t*	*goat*	*got*	
lose	*c*	*clues*	*close*	
crow	*n*	*crone*	*crown*	
ear	*p*	*peer*	*pear*	
		Total:		

Comments:

Table B2

Grapheme/Phoneme Addition Task: Condition 2 Response Sheet

Condition 2: Visual Presentation - Phonological Response Required

own
crow
me
ear
are
go
lose
bead

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
hoe	***s***	***show***	***shoe***	
four	***l***	***floor***	***flour***	
Test Items				
own	*t*	*tone*	*town*	
crow	*n*	*crone*	*crown*	
me	*t*	*meet*	*met*	
ear	*p*	*peer*	*pear*	
are	*c*	*car*	*care*	
go	*t*	*goat*	*got*	
lose	*c*	*clues*	*close*	
bead	*r*	*breed*	*bread*	
		Total:		

Comments:

Table B3

Grapheme/Phoneme Addition Task: Condition 3 Response Sheet

Condition 3: Auditory Presentation - Phonological Response Required

seat
are
owl
me
grid
ear
though
ski

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
hut	***r***	***heart***	***hurt***	
heap	***c***	***keep***	***cheap***	
Test Items				
seat	*w*	*sweet*	*sweat*	
are	*f*	*far*	*fare*	
owl	*b*	*bowel*	*bowl*	
me	*n*	*mean*	*men*	
grid	*n*	*grinned*	*grind*	
ear	*b*	*beer*	*bear*	
though	*r*	*throw*	*through*	
ski	*d*	*skied*	*skid*	
		Total:		

Comments:

Table B4

Grapheme/Phoneme Addition Task: Condition 4 Response Sheet

Condition 4: Visual Presentation - Orthographic Response Required

though
are
owl
seat
ear
ski
me
grid

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
hoe	***s***	***show***	***shoe***	
four	***l***	***floor***	***flour***	
Test Items				
though	*r*	*throw*	*through*	
are	*f*	*far*	*fare*	
owl	*b*	*bowel*	*bowl*	
seat	*w*	*sweet*	*sweat*	
ear	*b*	*beer*	*bear*	
ski	*d*	*skied*	*skid*	
me	*n*	*mean*	*men*	
grid	*n*	*grinned*	*grind*	

Total: ______

Comments:

Appendix C: Grapheme-Phoneme Deletion Task Stimuli

Table C1

Grapheme/Phoneme Deletion Task: Condition 1 Response Sheet

Condition 1: Auditory Presentation - Orthographic Response Required

cone
barge
pearl
pretty
thought
past
sweat
broad

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
dare	***d***	***air***	***are***	
boat	***t***	***bow***	***boa***	
Test Items				
cone	*c*	*own*	*one*	
barge	*g*	*bar*	*bare*	
pearl	*l*	*purr*	*pear*	
pretty	*r*	*pity*	*petty*	
thought	*final t*	*thaw*	*though*	
past	*s*	*part*	*pat*	
sweat	*w*	*set*	*seat*	
broad	*b*	*roared*	*road*	
		Total:		

Comments:

Table C2

Grapheme/Phoneme Deletion Task: Condition 2 Response Sheet

Condition 2: Visual Presentation - Phonological Response Required

past
sweat
broad
pearl
thought
pretty
cone
barge

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
stew	***t***	***sue***	***sew***	
gent	***n***	***jet***	***get***	
Test Items				
past	*s*	*part*	*pat*	
sweat	*w*	*set*	*seat*	
broad	*b*	*roared*	*road*	
pearl	*l*	*purr*	*pear*	
thought	*final t*	*thaw*	*though*	
pretty	*r*	*pity*	*petty*	
cone	*c*	*own*	*one*	
barge	*g*	*bar*	*bare*	
		Total:		

Comments:

Table C3

Grapheme/Phoneme Deletion Task: Condition 3 Response Sheet

Condition 3: Auditory Presentation - Phonological Response Required

beard
snow
meant
climb
bread
cast
hind
friend

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
dare	***d***	***air***	***are***	
boat	***t***	***bow***	***boa***	
Test Items				
beard	*d*	*beer*	*bear*	
snow	*s*	*no*	*now*	
meant	*t*	*men*	*mean*	
climb	*c*	*lime*	*limb*	
bread	*r*	*bed*	*bead*	
cast	*s*	*cart*	*cat*	
hind	*n*	*hide*	*hid*	
friend	*r*	*fend*	*fiend*	
		Total:		

Comments:

Table C4

Grapheme/Phoneme Deletion Task: Condition 4 Response Sheet

Condition 4: Visual Presentation - Orthographic Response Required

climb
hind
bread
beard
meant
friend
snow
cast

Word	*Letter*	*Phon response*	*Orth response*	*Other*
Practice Items				
stew	***t***	***sue***	***sew***	
gent	***n***	***jet***	***get***	
Test Items				
climb	*c*	*lime*	*limb*	
hind	*n*	*hide*	*hid*	
bread	*r*	*bed*	*bead*	
beard	*d*	*beer*	*bear*	
meant	*t*	*men*	*mean*	
friend	*r*	*fend*	*fiend*	
snow	*s*	*no*	*now*	
cast	*s*	*cart*	*cat*	
		Total:		

Comments:

Appendix D: Computer-Administered Task Stimuli

Table D1

Targets and Foils for the Orthographic Choice Task

Practice Target	Practice Foil
sheep	sheap
hole	hoal
skate	skait
sleep	sleap
nice	nise
please	pleese

Target	Foil
room	rume
young	yung
turtle	tertle
snow	snoe
take	taik
goat	gote
street	streat
answer	anser
between	betwean
deep	deap
easy	eazy
face	fase
heavy	hevvy
hurt	hert
lake	laik
need	nead
roar	rore
smoke	smoak
tape	taip
toward	toard
wait	wate
bowl	boal
clown	cloun
circus	sircus
wrote	wroat
word	wurd
coat	cote
rain	rane
store	stoar
wagon	wagun
believe	beleav
choose	chooze
dream	dreem
every	evry
few	fue
keep	keap
learn	lurnm
scare	scair
stream	streem
thumb	thum

Table D2

Targets and Foils for the Phonological Choice Task

Practice Target	Practice Foil
seet	seaf
thurd	thord
fead	feem
docter	doftor
thrue	threp
hoap	hote

Target	Foil
baik	bape
lait	lote
braive	broave
bloe	blog
kake	dake
trane	traif
broun	broan
fite	fipe
ferst	filst
ait	afe
klass	cliss
derty	dorty
eer	eap
flote	floap
hawl	harl
joak	jope
neer	nerr
plaice	plice
shurt	shart
teech	neach
tirn	turt
fense	felce
thair	theer
fether	fither
bote	boaf
bair	beal
caim	pame
naim	nade
gaim	gome
kard	carn
craul	crail
fearce	fairce
floar	ploor
leeve	meave
reech	reash
saif	saip
shaip	shate
strate	strale
tracter	trastor
werld	warld

Table D3

Targets and Foils for the Orthographic Awareness Task

Practice Target	Practice Foil
filk	filv
tolb	tolz
powl	lowp

Target	Foil
lund	dlun
fant	tanf
miln	milg
togn	togd
wolt	wolg
moke	moje
jofy	fojy
crif	cnif
blad	bnad
hift	hifl
gnup	gwup
nilt	nitl
clid	cdil
vism	visn

Appendix E: Grapheme-Phoneme Addition Instructions

Auditory Presentations

Place the easel in front of the child and expose the first practice word. Say to the child, "Now we are going to do a different kind of thing". If the deletion task has already been run say, "Instead of taking letters and sounds away from words we are going to add letters and sounds to words".

Auditory presentation first:

"In this task I want you to listen to some words. I am going ask you to add a letter to each word and tell me what the new word spells. This will be a different answer to when I ask you to add a sound to each word and tell me how the new word sounds."

Auditory presentation second:

If the visual conditions have already been run then say "I am going to say the words instead of showing them to you".

Auditory presentation/Orthographic response

Practice items:

1. "Think about how the word 'hut' is spelt. If you added the letter 'r' before the 't', what would the new word spell? The answer is a new word. The answer is 'hurt'. The answer 'hurt' does not sound much like the word 'hut' does it?"
2. "Think about how the word 'heap' is spelt. If you added the letter 'c' at the start of the word 'heap', what would the new word spell? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'cheap'."

Experimental Items:

For each stimulus word, say to the child: "Think of the word <word>. What would the word <word> spell if you added the letter <letter, specify position>?"

Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Auditory presentation/Phonological response

Practice items:

1. "Think about how the word 'hut' sounds. What would 'hut' sound like if you added an /r/ sound before the /t/. The answer is 'heart' which is different to 'hut' isn't it?"
2. "Think about how the word 'heap' sounds. What would the word 'heap' sound like if you added a /k/ sound at the start of the word? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'keep'."

Experimental items:

For each stimulus word, say to the child: "Think of the word <word>. What would the word <word> sound like if you added the sound <sound, specify position>?"

Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Visual Presentations

Place the easel in front of the child and expose the first practice word.

Say to the child, "Now we are going to do a different kind of thing".

If they have already done the deletion task then say, "Instead of taking letters and sounds away from words we are going to add letters and sounds to words".

Visual presentation first:

"In this task I am going to show you some words. I am going ask you to add a letter to each word and tell me what the new word spells. This will be a different answer to when I ask you to add a sound to each word and tell me how the new word sounds."

Visual presentation second:

If the auditory conditions have already been run then say "I am going to show you the words instead of saying them".

Visual presentation/Orthographic response

Practice items:

1. "Look at this word (hoe) but do not say it. What would this word spell if the letter 's' were added to the start of the word? The answer is a new word. The answer is 'shoe'. The answer 'shoe' doesn't sound much like the word 'hoe' does it?"
2. "Look at this word (four) but do not say it. What new word would this word spell if you added the letter 'l' after the 'f'? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'flour'."

Experimental items:

Expose the first experimental word. Say: "Look at this word but do not say it. What would this word spell if you added the letter <letter, specify position>?"

Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Visual presentation/Phonological response

Practice items:

1. "Look at this word (hoe) but do not say it. What would this word sound like if you added an /s/ sound at the start of the word? The answer is 'so' which is different to 'hoe' isn't it?"
2. "Look at this word (four) but do not say it. What would this word sound like if you added an /l/ sound after the /f/? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'floor'."

Experimental items:

Expose the first experimental word. Say: "Look at this word but do not say it. What would this word sound like if you added the sound <sound, specify position>?" Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Appendix F: Grapheme-Phoneme Deletion Instructions

Auditory presentations

Place the easel in front of the child and expose the first practice word.

Say to the child, "Now we are going to do a different kind of thing".

If the addition task has already been run say, "Instead of adding letters and sounds to from words we are going to take letters and sounds away from words".

Auditory presentation first:

"In this task I want you to listen to some words. I am going ask you to take away a letter from each word and tell me what the new word spells. This will be a different answer to when I ask you to take away a sound from each word and tell me how the new word sounds."

Auditory presentation second:

If the visual conditions have already been run then say "I am going to say the words instead of showing them to you".

Auditory presentation/Orthographic response

Practice items:

1. "Think about how the word 'dare' is spelt. If you took away the letter 'd', what would the new word spell? The answer is a new word. The answer is 'are'. The answer 'are' does not sound much like the word 'dare' does it?"
2. "Think about how the word 'boat' is spelt. If you took away the letter 't', what would the new word spell? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'boa'."

Experimental Items:

For each stimulus word, say to the child: "Think of the word <word>. What would the word <word> spell if you took away the letter <letter, specify position>?" Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Auditory presentation/Phonological response

Practice items:

1. "Think about how the word 'dare' sounds. What would 'dare' sound like if you took away the /d/ sound. The answer is 'air' which is different to 'dare' isn't it?"
2. "Think about how the word 'boat' sounds. What would the word 'boat' sound like if you took away the /t/ sound? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'bow'."

Experimental items:

For each stimulus word, say to the child: "Think of the word <word>. What would the word <word> sound like if you took away the sound <sound, specify position>?" Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Visual presentations

Place the easel in front of the child and expose the first practice word.

Say to the child, "Now we are going to do a different kind of thing".

If they have already done the addition task then say "Instead of adding letters and sounds to words we are going to take away letters and sounds from words".

Visual presentation first:

"In this task I am going to show you some words. I am going ask you to take away a letter from each word and tell me what the new word spells. This will be a different answer to when I ask you to take away a sound from each word and tell me how the new word sounds."

Visual presentation second:

If the auditory conditions have already been run then say "I am going to show you the words instead of saying them".

Visual presentation/Orthographic response

Practice items:

1. "Look at this word (stew) but do not say it. If you took away the letter 't', what would the new word spell? The answer is a new word. The answer is 'sew'. The answer 'sew' doesn't sound much like the word 'stew' does it?"
2. "Look at this word (gent) but do not say it. If you took away the letter 'n', what would the new word spell? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'get'."

Experimental items:

Expose the first experimental word. Say: "Look at this word but do not say it. What would this word spell if you took away the letter <letter, specify position>?"
Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Visual presentation/Phonological response

Practice items:

1. "Look at this word (stew) but do not say it. What would this word sound like if you took away the /t/ sound? The answer is 'sue' which is different to 'stew'."
2. "Look at this word (gent) but do not say it. What would this word sound like if you took away the /n/ sound? [Allow the child time to respond] That's right [or "No" if incorrect], the answer is 'jet'."

Experimental items:

Expose the first experimental word. Say: "Look at this word but do not say it. What would this word sound like if you took away the sound < sound, specify position>?"
Tick the response sheet indicating the response the child made and if neither response was made, write down the child's response in the 'other' column. If the child says more than one word, write them all down and indicate the order they were said. Continue with the remaining stimuli in this condition.

Appendix G: Instructions for Computer-Administered Tasks

Phonological Choice Task

Say to the child: "Some words are going to come up on the computer screen two at a time. Neither of the words are real words but one of them sounds like a real word. If you think it is the word on the left side of the screen (point) press the z button. If you think the word on the right sounds like a real word (point) press the ? button". Run through the practice items and ensure that the child understands the task. Then go on and run the 40 experimental items.

Orthographic Choice Task

Say to the child: "Some words are going to come up on the computer screen two at a time. Both of the words sound like a real word but only one of them is a real word. If you think the word on the left side of the screen is the real word (point) press the z button. If you think the word on the right side of the screen is a real word (point) press the ? button". Run through the practice items and ensure that the child understands the task. Then go on and run the 40 experimental items.

Word-likeness task

Say to the child: "Some words are going to come up on the computer screen two at a time. The words are made up words and neither of them sounds like a real word. Choose which one could be a word or looks like a word. If you think it is the word on the left side of the screen press the z button. If you think the word on the right sounds like a real word press the ? button". Run through the practice items and ensure that the child understands the task. Then go on and run the experimental items.

Appendix H: Analysis of Variance for the Average Delay in Months between Time 1 and Time 2 Data Collection

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group	2	7.88	89	6.71	1.17	0.31
Cohort	2	76.79	89	6.71	11.44	<.0001*
Group x Cohort	4	24.06	89	6.71	3.59	0.01*

*$p<.05$.

Appendix I: ANOVA Tables for Longitudinal Data

Table I1

Analysis of Variance for Word Identification and Word Attack W Scores

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	24788.79	89	163.15	151.94	<.0001*
Cohort (C)	2	15126.69	89	163.15	92.72	<.0001*
Time (Ti)	1	27733.44	89	54.11	512.58	<.0001*
Task (Ta)	1	413.17	89	81.30	5.08	0.03*
G x C	4	541.54	89	163.15	3.32	0.01*
G x Ti	2	2071.68	89	54.11	38.29	<.0001*
C x Ti	2	1119.61	89	54.11	20.69	<.0001*
G x Ta	2	4618.78	89	81.30	56.81	<.0001*
C x Ta	2	3205.57	89	81.30	39.43	<.0001*
Ti x Ta	1	4650.39	89	49.94	93.12	<.0001*
G x C x Ti	4	167.16	89	54.11	3.09	0.02*
G x C x Ta	4	287.32	89	81.30	3.53	0.01*
G x Ti x Ta	2	492.60	89	49.94	9.86	<.001*
C x Ti x Ta	2	733.37	89	49.94	14.69	<.0001*
G x C x Ti x Ta	4	53.90	89	49.94	1.08	0.37

**p*<.05.

Table I2

Analysis of Variance for the Martin and Pratt Nonword Test Raw Scores

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	5339.98	89	80.72	66.16	<.0001*
Cohort (C)	2	1673.40	89	80.72	20.72	<.0001*
Time (Ti)	1	1265.50	89	15.56	81.32	<.0001*
G x C	4	156.21	89	80.72	1.94	0.11
G x Ti	2	256.38	89	15.56	16.48	<.0001*
C x Ti	2	98.06	89	15.56	6.30	<.01*
G x C x Ti	4	5.34	89	15.56	0.34	0.85

**p*<.05.

Table I3

Analysis of Variance for Regular and Irregular Word Reading Raw Scores

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	1032.87	88	13.84	74.62	<.0001*
Cohort (C)	2	837.37	88	13.84	60.50	<.0001*
Time (Ti)	1	1697.93	88	5.70	298.14	<.0001*
Task (Ta)	1	2081.01	88	6.40	324.94	<.0001*
G x C	4	83.47	88	13.84	6.03	<.001*
G x Ti	2	228.88	88	5.70	40.19	<.0001*
C x Ti	2	235.59	88	5.70	41.37	<.0001*
G x Ta	2	41.91	88	6.40	6.54	<.01 *
C x Ta	2	15.58	88	6.40	2.43	0.09
Ti x Ta	1	45.55	88	2.47	18.46	<.0001*
G x C x Ti	4	53.18	88	5.70	9.34	<.0001*
G x C x Ta	4	6.96	88	6.40	1.09	0.37
G x Ti x Ta	2	5.24	88	2.47	2.12	0.13
C x Ti x Ta	2	1.87	88	2.47	0.76	0.47
G x C x Ti x Ta	4	0.93	88	2.47	0.38	0.83

*$p<.05$.

Table I4

Analysis of Variance for Passage Comprehension W Scores

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	6788.23	87	135.70	50.03	<.0001*
Cohort (C)	2	4169.47	87	135.70	30.73	<.0001*
Time (Ti)	1	8511.25	87	35.24	241.55	<.0001*
G x C	4	570.64	87	135.70	4.21	<.01 *
G x Ti	2	132.75	87	35.24	3.77	0.03*
C x Ti	2	101.36	87	35.24	2.88	0.06
G x C x Ti	4	16.15	87	35.24	0.46	0.77

*$p<.05$.

Table I5

Analysis of Variance for Listening Comprehension Raw Scores

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	4173.32	87	145.43	28.70	<.0001*
Cohort (C)	2	1376.54	87	145.43	9.47	<.001 *
Time (Ti)	1	6008.57	87	42.50	141.38	<.0001*
G x C	4	132.48	87	145.43	0.91	0.46
G x Ti	2	143.71	87	42.50	3.38	0.04*
C x Ti	2	77.78	87	42.50	1.83	0.17
G x C x Ti	4	58.88	87	42.50	1.39	0.25

$^*p<.05$.

Table I6

Analysis of Variance for Addition and Deletion Task Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	514.22	89	12.14	42.37	<.0001*
Cohort (C)	2	221.08	89	12.14	18.22	<.0001*
Time (Ti)	1	393.11	89	4.95	79.39	<.0001*
Task (Ta)	1	39.67	89	2.54	15.60	<.001*
Modality (M)	1	25.34	89	2.51	10.09	<.01*
Strategy (S)	1	57.17	89	10.61	5.39	0.02*
G x C	4	10.40	89	12.14	0.86	0.49
G x Ti	2	30.01	89	4.95	6.06	<.01*
C x Ti	2	1.30	89	4.95	0.26	0.77
G x Ta	2	4.98	89	2.54	1.96	0.15
C x Ta	2	3.29	89	2.54	1.29	0.28
Ti x Ta	1	2.38	89	1.41	1.69	0.20
G x M	2	1.20	89	2.51	0.48	0.62
C x M	2	1.35	89	2.51	0.54	0.29
Ti x M	1	4.01	89	1.48	2.72	0.10
Ta x M	1	9.22	89	1.93	4.78	0.03*
G x S	2	16.15	89	10.61	1.52	0.22
C x S	2	33.74	89	10.61	3.18	0.05
Ti x S	1	6.80	89	2.39	2.85	0.10
Ta x S	1	0.15	89	2.69	0.06	0.81
M x S	1	632.81	89	2.38	266.01	<.0001*
G x C x Ti	4	3.84	89	4.95	0.78	0.54
G x C x Ta	4	0.65	89	2.54	0.25	0.91
G x Ti x Ta	2	1.42	89	1.41	1.01	0.37
C x Ti x Ta	2	1.99	89	1.41	1.41	0.25
G x C x M	4	1.51	89	2.51	0.60	0.66
G x Ti x M	2	0.43	89	1.48	0.29	0.75
C x Ti x M	2	0.61	89	1.48	0.41	0.66
G x Ta x M	2	9.33	89	1.93	4.84	0.01*
C x Ta x M	2	1.80	89	1.93	0.93	0.40
Ti x Ta x M	1	24.00	89	1.89	12.70	<.01*
G x C x S	4	11.54	89	10.61	1.09	0.37
G x Ti x S	2	11.67	89	2.39	4.88	0.01*
C x Ti x S	2	2.32	89	2.39	0.97	0.38
G x Ta x S	2	9.84	89	2.69	3.65	0.03*
C x Ta x S	2	9.86	89	2.69	3.66	0.03*
Ti x Ta x S	1	3.10	89	2.34	1.32	0.25
G x M x S	2	21.78	89	2.38	9.16	<.001*
C x M x S	2	10.07	89	2.38	4.23	0.02*
Ti x M x S	1	38.90	89	1.46	26.64	<.0001*
Ta x M x S	1	38.83	89	1.42	27.32	<.0001*
G x C x Ti x Ta	4	2.35	89	1.41	1.67	0.16
G x C x Ti x M	4	2.22	89	1.48	1.50	0.21

G x C x Ta x M	4	1.24	89	1.93	0.64	0.63
G x Ti x Ta x M	2	3.04	89	1.89	1.61	0.21
C x Ti x Ta x M	2	0.55	89	1.89	0.29	0.75
G x C x Ti x S	4	4.18	89	2.39	1.75	0.15
G x C x Ta x S	4	1.96	89	2.69	0.73	0.58
G x Ti x Ta x S	2	3.97	89	2.34	1.69	0.19
C x Ti x Ta x S	2	5.37	89	2.34	2.29	0.11
G x C x M x S	4	1.99	89	2.38	0.84	0.51
G x Ti x M x S	2	2.72	89	1.46	1.86	0.16
C x Ti x M x S	2	6.00	89	1.46	4.11	0.02*
G x Ta x M x S	2	2.56	89	1.42	1.80	0.17
C x Ta x M x S	2	0.16	89	1.42	0.11	0.89
Ti x Ta x M x S	1	0.23	89	1.19	0.02	0.66
G x C x Ti x Ta x M	4	2.19	89	1.89	1.16	0.33
G x C x Ti x Ta x S	4	3.75	89	2.34	1.60	0.18
G x C x Ti x M x S	4	0.65	89	1.46	0.45	0.77
G x C x Ta x M x S	4	1.00	89	1.42	0.70	0.59
G x Ti x Ta x M x S	2	2.12	89	1.19	1.78	0.17
C x Ti x Ta x M x S	2	0.37	89	1.19	0.31	0.73
G x C x Ti x Ta x M x S	4	0.63	89	1.19	0.53	0.72

*p<.05.

Table I7

Analysis of Variance for Addition Task Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	227.20	89	7.40	30.71	<.0001*
Cohort (C)	2	89.81	89	7.40	12.14	<.0001*
Time (Ti)	1	167.16	89	3.17	52.69	<.0001*
Modality (M)	1	32.56	89	2.00	16.26	<.001*
Strategy (S)	1	25.72	89	7.54	3.41	0.07
G x C	4	4.97	89	7.40	0.67	0.61
G x Ti	2	9.69	89	3.17	3.06	0.05
C x Ti	2	0.03	89	3.17	0.01	0.99
G x M	2	8.58	89	2.00	4.28	0.02*
C x M	2	0.65	89	2.00	0.32	0.72
Ti x M	1	23.81	89	1.81	13.16	<.001*
G x S	2	14.24	89	7.54	1.89	0.16
C x S	2	34.85	89	7.54	4.62	0.01*
Ti x S	1	0.36	89	2.66	0.14	0.71
M x S	1	179.06	89	2.00	89.59	<.0001*
G x C x Ti	4	3.75	89	3.17	1.18	0.33
G x C x M	4	2.17	89	2.00	1.08	0.37
G x Ti x M	2	1.93	89	1.81	1.06	0.35
C x Ti x M	2	1.16	89	1.81	0.64	0.53
G x C x S	4	7.65	89	7.54	1.01	0.40
G x Ti x S	2	14.41	89	2.66	5.42	0.01*
C x Ti x S	2	7.15	89	2.66	2.69	0.08
G x M x S	2	7.71	89	2.00	3.86	0.03*
C x M x S	2	4.33	89	2.00	2.17	0.12
Ti x M x S	1	16.56	89	1.47	11.31	<.01*
G x C x Ti x M	4	1.45	89	1.81	0.80	0.53
G x C x Ti x S	4	3.36	89	2.66	1.26	0.29
G x C x M x S	4	0.15	89	2.00	0.08	0.99
G x Ti x M x S	2	0.78	89	1.47	0.53	0.59
C x Ti x M x S	2	2.32	89	1.47	1.58	0.21
G x C x Ti x M x S	4	0.69	89	1.47	0.47	0.76

*p<.05.

Table I8

Analysis of Variance for Deletion Task Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	292.00	89	7.28	40.11	<.0001*
Cohort (C)	2	134.56	89	7.28	18.48	<.0001*
Time (Ti)	1	228.34	89	3.19	71.59	<.0001*
Modality (M)	1	2.00	89	2.44	0.82	0.37
Strategy (S)	1	31.60	89	5.76	5.45	0.02*
G x C	4	6.07	89	7.28	0.83	0.51
G x Ti	2	21.74	89	3.19	6.81	<.01*
C x Ti	2	3.25	89	3.19	1.02	0.37
G x M	2	1.95	89	2.44	0.80	0.45
C x M	2	2.50	89	2.44	1.03	0.36
Ti x M	1	4.20	89	1.56	2.70	0.10
G x S	2	11.75	89	5.76	2.04	0.14
C x S	2	8.75	89	5.76	1.52	0.22
Ti x S	1	9.54	89	2.07	4.60	0.04*
M x S	1	492.58	89	1.80	273.43	<.0001*
G x C x Ti	4	2.45	89	3.19	0.77	0.55
G x C x M	4	0.58	89	2.44	0.24	0.92
G x Ti x M	2	1.55	89	1.56	0.99	0.37
C x Ti x M	2	0.00	89	1.56	0.00	1.00
G x C x S	4	5.84	89	5.76	1.01	0.41
G x Ti x S	2	1.23	89	2.07	0.59	0.56
C x Ti x S	2	0.54	89	2.07	0.26	0.77
G x M x S	2	16.63	89	1.80	9.23	<.001*
C x M x S	2	5.90	89	1.80	3.28	0.04*
Ti x M x S	1	22.57	89	1.18	19.07	<.0001*
G x C x Ti x M	4	2.96	89	1.56	1.90	0.12
G x C x Ti x S	4	4.57	89	2.07	2.20	0.08
G x C x M x S	4	2.83	89	1.80	1.57	0.19
G x Ti x M x S	2	4.06	89	1.18	3.43	0.04*
C x Ti x M x S	2	4.05	89	1.18	3.42	0.04*
G x C x Ti x M x S	4	0.59	89	1.18	0.50	0.74

*p<.05.

Table I9

Analysis of Variance for Addition Task Crossed Responses

Effect	df effect	MS effect	df error	MS error	F	p
Group (G)	2	98.48	89	5.66	17.39	<.0001*
Cohort (C)	2	12.93	89	5.66	2.28	0.11
Time (Ti)	1	107.25	89	2.96	36.22	<.0001*
Modality (M)	1	74.63	89	1.83	40.72	<.0001*
Strategy (S)	1	14.31	89	6.90	2.07	0.15
G x C	4	4.85	89	5.66	0.86	0.49
G x Ti	2	2.81	89	2.96	0.95	0.39
C x Ti	2	5.69	89	2.96	1.92	0.15
G x M	2	10.27	89	1.83	5.60	0.01*
C x M	2	2.26	89	1.83	1.23	0.30
Ti x M	1	16.27	89	1.69	9.65	<.01*
G x S	2	7.19	89	6.90	1.04	0.36
C x S	2	23.75	89	6.90	3.44	0.04*
Ti x S	1	0.01	89	2.32	0.00	0.96
M x S	1	196.39	89	1.91	103.00	<.0001*
G x C x Ti	4	3.67	89	2.96	1.24	0.30
G x C x M	4	3.66	89	1.83	2.00	0.10
G x Ti x M	2	1.46	89	1.69	0.87	0.42
C x Ti x M	2	2.92	89	1.69	1.73	0.18
G x C x S	4	2.94	89	6.90	0.43	0.79
G x Ti x S	2	13.38	89	2.32	5.76	<.01*
C x Ti x S	2	12.51	89	2.32	5.39	0.01*
G x M x S	2	7.21	89	1.91	3.78	0.03*
C x M x S	2	6.58	89	1.91	3.45	0.04*
Ti x M x S	1	13.89	89	1.62	8.55	<.01*
G x C x Ti x M	4	1.08	89	1.69	0.64	0.64
G x C x Ti x S	4	3.12	89	2.32	1.34	0.26
G x C x M x S	4	0.53	89	1.91	0.28	0.89
G x Ti x M x S	2	0.22	89	1.62	0.14	0.87
C x Ti x M x S	2	1.20	89	1.62	0.74	0.48
G x C x Ti x M x S	4	0.20	89	1.62	0.13	0.97

*p<.05.

Table I10

Analysis of Variance for Deletion Task Crossed Responses

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	83.50	89	4.83	17.29	<.0001*
Cohort (C)	2	21.83	89	4.83	4.52	0.01*
Time (Ti)	1	100.23	89	2.56	39.10	<.0001*
Modality (M)	1	68.93	89	1.85	37.26	<.0001*
Strategy (S)	1	40.98	89	5.02	8.16	0.01*
G x C	4	9.62	89	4.83	1.99	0.10
G x Ti	2	3.53	89	2.56	1.38	0.26
C x Ti	2	0.73	89	2.56	0.28	0.75
G x M	2	0.45	89	1.85	0.24	0.79
C x M	2	1.34	89	1.85	0.72	0.49
Ti x M	1	0.01	89	1.49	0.01	0.93
G x S	2	9.32	89	5.02	1.86	0.16
C x S	2	6.88	89	5.02	1.37	0.26
Ti x S	1	4.81	89	1.95	2.47	0.12
M x S	1	498.11	89	1.62	307.45	<.0001*
G x C x Ti	4	1.41	89	2.56	0.55	0.70
G x C x M	4	0.54	89	1.85	0.29	0.88
G x Ti x M	2	0.98	89	1.49	0.66	0.52
C x Ti x M	2	1.36	89	1.49	0.91	0.41
G x C x S	4	8.22	89	5.02	1.64	0.17
G x Ti x S	2	2.19	89	1.95	1.12	0.33
C x Ti x S	2	1.65	89	1.95	0.85	0.43
G x M x S	2	13.31	89	1.62	8.21	<.01*
C x M x S	2	4.27	89	1.62	2.63	0.08
Ti x M x S	1	23.51	89	1.20	19.65	<.0001*
G x C x Ti x M	4	2.17	89	1.49	1.46	0.22
G x C x Ti x S	4	4.05	89	1.95	2.08	0.09
G x C x M x S	4	5.74	89	1.62	3.54	0.01*
G x Ti x M x S	2	3.85	89	1.20	3.22	0.05*
C x Ti x M x S	2	5.15	89	1.20	4.30	0.02*
G x C x Ti x M x S	4	0.89	89	1.20	0.74	0.57

$^*p<.05$.

Table I11

Analysis of Variance for Deletion Task Crossed Responses for Cohort A

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	9.14	28	3.36	2.72	0.08
Time (Ti)	1	22.31	28	3.29	6.78	0.02*
Modality (M)	1	19.66	28	1.54	12.77	<.01*
Strategy (S)	1	4.53	28	4.16	1.16	0.29
G x Ti	2	1.40	28	3.29	0.42	0.66
G x M	2	0.06	28	1.54	0.04	0.96
Ti x M	1	1.44	28	1.90	0.76	0.39
G x S	2	7.84	28	4.16	1.88	0.17
Ti x S	1	0.01	28	1.86	0.00	0.96
M x S	1	215.24	28	1.15	187.00	<.0001*
G x Ti x M	2	0.16	28	1.9	0.08	0.92
G x Ti x S	2	5.64	28	1.86	3.03	0.06
G x M x S	2	3.23	28	1.15	2.81	0.08
Ti x M x S	1	0.13	28	1.61	0.08	0.78
G x Ti x M x S	2	0.81	28	1.61	0.50	0.61

*$p<.05$.

Table I12

Analysis of Variance for Deletion Task Crossed Responses for Cohort B

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	37.86	30	5.13	7.38	<.01*
Time (Ti)	1	35.68	30	2.82	12.67	<.01*
Modality (M)	1	36.98	30	1.59	23.25	<.0001*
Strategy (S)	1	4.65	30	4.34	1.07	0.31
G x Ti	2	0.32	30	2.82	0.11	0.89
G x M	2	1.45	30	1.59	0.91	0.41
Ti x M	1	0.00	30	1.38	0.00	0.96
G x S	2	4.22	30	4.34	0.97	0.39
Ti x S	1	1.24	30	2.90	0.43	0.52
M x S	1	161.59	30	1.83	88.29	<.0001*
G x Ti x M	2	4.54	30	1.38	3.29	0.05
G x Ti x S	2	2.32	30	2.90	0.80	0.46
G x M x S	2	17.06	30	1.83	9.32	<.001*
Ti x M x S	1	9.93	30	1.11	8.95	0.01*
G x Ti x M x S	2	3.08	30	1.11	2.78	0.08

*$p<.05$.

Table I13

Analysis of Variance for Deletion Task Crossed Responses for Cohort C

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	57.87	31	5.86	9.87	<.001*
Time (Ti)	1	44.87	31	1.66	27.01	<.0001*
Modality (M)	1	14.96	31	2.38	6.28	0.02*
Strategy (S)	1	46.72	31	6.45	7.24	0.01*
G x Ti	2	4.69	31	1.66	2.82	0.08
G x M	2	0.07	31	2.38	0.03	0.97
Ti x M	1	1.28	31	1.22	1.05	0.31
G x S	2	13.61	31	6.45	2.11	0.14
Ti x S	1	7.19	31	1.11	6.48	0.02*
M x S	1	125.31	31	1.84	68.08	<.0001*
G x Ti x M	2	0.63	31	1.22	0.52	0.60
G x Ti x S	2	2.56	31	1.11	2.31	0.12
G x M x S	2	4.08	31	1.84	2.22	0.13
Ti x M x S	1	25.09	31	0.91	27.68	<.0001*
G x Ti x M x S	2	1.84	31	0.91	2.03	0.15

*$p<.05$.

Table I14

Analysis of Variance for Orthographic and Phonological Choice Task Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	872.60	87	22.03	39.61	<.0001*
Cohort (C)	2	693.93	87	22.03	31.50	<.0001*
Time (Ti)	1	961.34	87	14.00	68.67	<.0001*
Task (Ta)	1	8110.89	87	15.84	512.07	<.0001*
G x C	4	66.74	87	22.03	3.03	0.02*
G x Ti	2	128.42	87	14.00	9.17	<.001*
C x Ti	2	58.47	87	14.00	4.18	0.02*
G x Ta	2	244.36	87	15.84	15.43	<.0001*
C x Ta	2	77.96	87	15.84	4.92	0.01*
Ti x Ta	1	25.40	87	11.26	2.26	0.14
G x C x Ti	4	12.12	87	14.00	0.87	0.49
G x C x Ta	4	20.40	87	15.84	1.29	0.28
G x Ti x Ta	2	45.89	87	11.26	4.08	0.02*
C x Ti x Ta	2	57.14	87	11.26	5.08	0.01*
G x C x Ti x Ta	4	40.63	87	11.26	3.61	0.01*

*$p<.05$.

Table I15

Analysis of Variance for Phonological Choice Task Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	1001.11	87	27.84	35.96	<.0001*
Cohort (C)	2	600.51	87	27.84	21.27	<.0001*
Time (Ti)	1	649.64	87	19.30	33.62	<.0001*
G x C	4	46.74	87	27.84	1.68	0.16
G x Ti	2	92.71	87	19.30	4.80	0.01*
C x Ti	2	18.08	87	19.30	0.94	0.40
G x C x Ti	4	35.16	87	19.30	1.82	0.13

*$p<.05$.

Table I16

Analysis of Variance for Orthographic Choice Task Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	123.93	88	9.96	12.44	<.0001*
Cohort (C)	2	169.74	88	9.96	17.04	<.0001*
Time (Ti)	1	338.71	88	5.89	57.52	<.0001*
G x C	4	44.51	88	9.96	4.47	<.01*
G x Ti	2	84.43	88	5.89	14.34	<.0001*
C x Ti	2	98.45	88	5.89	16.72	<.0001*
G x C x Ti	4	18.99	88	5.89	3.23	0.02*

*$p<.05$.

Table I17

Analysis of Variance for Orthographic Choice Task Accuracy corrected for Spelling

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	1079.82	66	217058	4.96	0.01*
Cohort (C)	2	1103.59	66	217.58	5.07	0.01*
Time (Ti)	1	1877.99	66	186.43	10.07	<.01*
Spelling Accuracy (S)	1	334.14	66	96.03	3.48	0.07
G x C	4	418.02	66	217.58	1.92	0.12
G x Ti	2	616.07	66	186.43	3.30	0.04*
C x Ti	2	850.73	66	186.43	4.56	0.01*
G x S	2	298.19	66	96.03	3.11	0.05
C x S	2	15.62	66	96.03	0.16	0.85
Ti x S	1	14.86	66	104.26	0.14	0.71
G x C x Ti	4	91.97	66	186.43	0.49	0.74
G x C x S	4	71.34	66	96.03	0.74	0.57
G x Ti x S	2	87.00	66	104.26	0.83	0.44
C x Ti x S	2	20.02	66	104.26	0.19	0.83
G x C x Ti x S	4	65.64	66	104.26	0.63	0.64

$^*p<.05$.

Table I18

Analysis of Variance for Orthographic and Phonological Choice Task Reaction Time

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	1476921.00	87	405550.60	3.64	0.03*
Cohort (C)	2	28420.01	87	405550.60	0.07	0.93
Time (Ti)	1	1625489.00	87	136662.90	11.89	<.001*
Task (Ta)	1	51047168.00	87	135464.00	376.83	<.0001*
G x C	4	671147.90	87	405550.60	1.65	0.17
G x Ti	2	86861.49	87	136662.90	0.64	0.53
C x Ti	2	3887.44	87	136662.90	0.03	0.97
G x Ta	2	332120.20	87	135464.00	2.45	0.09
C x Ta	2	1207410.00	87	135464.00	8.91	<.001*
Ti x Ta	1	451621.30	87	78959.45	5.72	0.02*
G x C x Ti	4	131869.80	87	136662.90	0.96	0.43
G x C x Ta	4	323491.30	87	135464.00	2.39	0.06
G x Ti x Ta	2	206781.80	87	78959.45	2.62	0.08
C x Ti x Ta	2	323841.40	87	78959.45	4.10	0.02*
G x C x Ti x Ta	4	51970.28	87	78959.45	0.66	0.62

$^*p<.05$.

Table I19

Analysis of Variance for Orthographic Awareness Accuracy

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	11.16	88	4.92	2.27	0.11
Cohort (C)	2	13.29	88	4.92	2.70	0.07
G x C	4	2.85	88	4.92	0.58	0.68

Table I20

Analysis of Variance for Orthographic Awareness Reaction Time

Effect	df effect	MS effect	df error	MS error	*F*	*p*
Group (G)	2	96573.13	88	264354.80	0.37	0.70
Cohort (C)	2	261512.70	88	264354.80	0.99	0.38
G x C	4	762326.20	88	264354.80	2.88	0.03*

*p<.05.